

JET AIRCRAFT
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ADDITIONAL AERONAUTICAL BOOKS

BY CHARLES EDWARD CHAPEL

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AIRCRAFT ELECTRICITY FOR THE MECHANIC

AND CO-EDITOR ON THIRD EDITION OF BAUGHMAN'S:

AVIATION DICTIONARY & REFERENCE GUIDE

JET AIRCRAFT

SIMPLIFIED

BY

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By

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CHAPTER I

THE DISCOVERY OF JET PROPULSION

HERO AND HIS AEOLIPILE

About the year 120 B.C., there lived in Alexandria, Egypt, a man named Hero, who was highly skilled in mathematics and physics. He invented many things, including a water clock, a hydraulic organ, a compressed-air catapult, and a peculiar device which he called an *aeolipile*.

We do not know exactly how it was built, but it probably resembled the apparatus shown in Fig. 1. Water was boiled in a closed kettle over a fire. Two metal tubes supported a hollow metal ball which rotated about the ends of these tubes. Leading out from the ball were shorter tubes, bent at right angles and open to the air at one end. When the water in the kettle boiled, the steam came up the tubes on both sides of the ball, entered the ball, and escaped through the short, bent tubes, thus causing the ball to rotate rapidly about its horizontal axis.

Assuming that this was the construction of the aeolipile, Hero invented the first known jet engine. However, there is another story which says that his ball rotated about its vertical axis and was operated by hot air. If this is true, Hero invented a primitive form of the gas turbine.

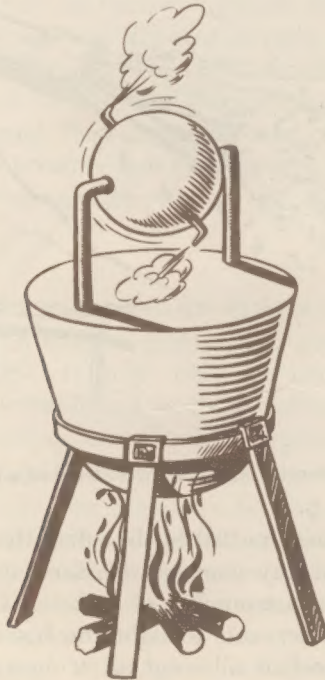


Fig. 1. The *aeolipile* invented by Hero, of Alexandria, Egypt, about 120 B.C.

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EARLY CHINESE ROCKETS

The rocket is a jet-propulsion device. The early Chinese rockets were propelled by *black powder*, which was simply a mixture of charcoal, sulphur and saltpeter. In this form, gunpowder was used from the time of its discovery until better explosives were developed in the first quarter of the present century. However, black powder is still widely used for many special purposes, such as blasting, firecrackers, etc,

Gunpowder was obviously discovered before rockets could be propelled by it. We do not know the date or place of its first use, but it is certain that the English monk, Roger Bacon, mentioned it in his writings in 1267, and that it was mentioned as early as 846. The first record of its actual use in Europe was made by Bishop Albertus Magnus who said in 1280 that gunpowder was employed during the siege of Seville, Spain, in 1247.

Before that, many fiery mixtures were known to the ancient people of China, India, Greece, Arabia, and other countries of the Mediterranean and the Far East. Some of these substances were a form of Greek fire, a composition which burns under water. Other substances undoubtedly had explosive tendencies.

Chinese records contain an account of a battle in the year 1232, when "flying fire arrows" were used to frighten the enemy soldiers who were attacking a walled city. It is believed that these were actually rockets mounted on arrows to provide stability in flight, and probably resembled the one shown in Fig. 2.



Fig. 2. Rockets mounted on arrows were used in a Chinese battle in 1232.

There is another Chinese record to the effect that during the Ming dynasty, about the year 1400, a wealthy man had his servants mount ski-like runners on the legs of a chair and attach a number of rockets, as shown in Fig. 3. He sat in the chair and ordered his servants to light the fuses of the rockets. The chair moved forward, but the rockets all went off at once and blew the experimenter and his chair into eternity. This may have been the first attempt at practical jet propulsion for a passenger-carrying vehicle.

THE DISCOVERY OF JET PROPULSION

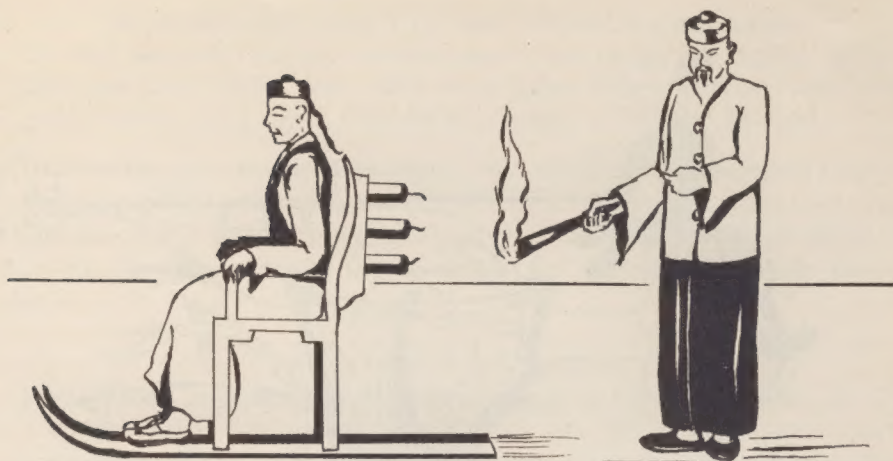


Fig. 3. About the year 1400, a wealthy Chinese devised a method of rocket propulsion which unfortunately blew him into eternity.

EARLY ITALIAN EXPERIMENTS

In 1550, Leonardo da Vinci, an Italian painter who was also a sculptor, architect, musician, poet, engineer, mathematician, and philosopher, sketched a device which could be installed in a chimney where the upward movement of the hot gases from a fireplace would turn a spit for roasting meat. This, too, was an application of jet propulsion.

In 1629, Giovanni Branca, an Italian engineer, announced the invention of a steam turbine. A jet of steam was directed at right angles to a horizontal fan wheel mounted on a vertical spindle. The steam struck the open vanes arranged around the circumference of the fan wheel and drove the spindle very rapidly. By means of cogwheel gearing, the rotational speed of the spindle was reduced to drive a stamp mill. It is possible that the use of a high rotational speed and reduction gearing in modern turbojet engines had its origin in Branca's early turbine.

SIR ISAAC NEWTON AND HIS STEAM CARRIAGE

Sir Isaac Newton was an English philosopher, mathematician and physicist who lived from 1642 to 1727. In July, 1687, his book, *Philosophiae Naturalis Principia Mathematica*, was published in three volumes. In this work, he explained his three laws of motion, one of which explains jet propulsion.

Another author wrote comments on Newton's book and included an illustration similar to Fig. 4 to show how Newton's Second Law of Motion could be applied. This was a four-wheeled carriage with a spherical boiler mounted over a fire box. Steam produced by boiling water was directed to the rear of the carriage through a nozzle. In this manner, the reaction of the jet of steam drove the carriage forward. The driver controlled the speed by means of a rod that operated a valve in the nozzle. Although it is believed that the steam wagon was designed by a Dutchman, Willem Jakobsz Gravesande, it is usually referred to in textbooks as "Newton's Steam Carriage."

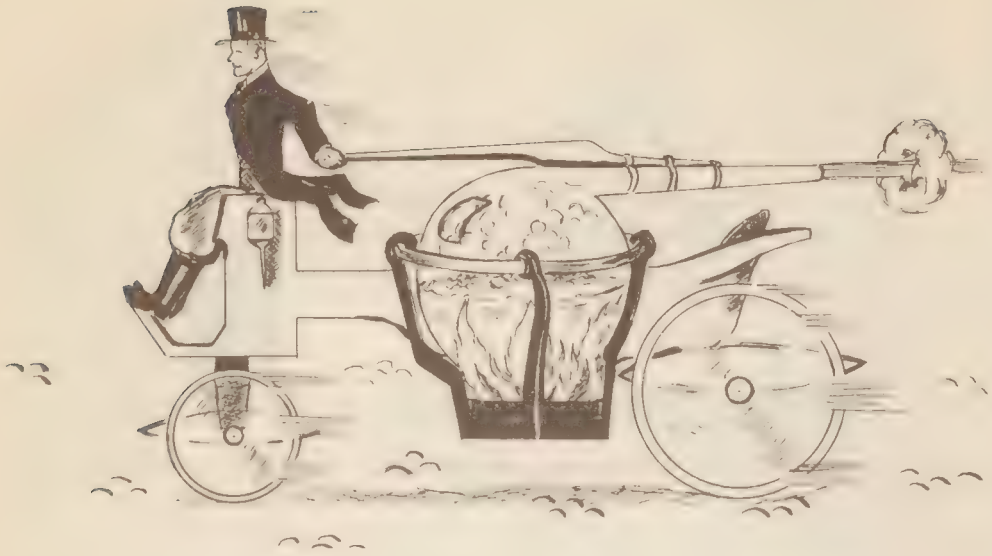


Fig. 4. Newton's steam carriage.

NEWTON'S THREE LAWS OF MOTION

Newton gave the world three laws of motion, but he presented them in technical language which is difficult to simplify. The first law says that every body left to itself, free from the action of other bodies, will, if at rest, remain at rest, or, if moving, will continue to move with constant velocity. This law is of general application and pertains to jet propulsion no more than it does to other forms of motion, hence it is of little interest to us in our discussion of the development of jet propulsion.

Newton's second law applies to all forms of jet propulsion. Unless your high school physics is fresh in your mind, skip this paragraph and come back to it after you have read the remainder of the book. The second law states that the rate of change of *momentum* (the mass of a body multiplied by its velocity at that instant) of a body measures in direction and magnitude the force acting on it. In other words, a force is created by a change of momentum, and this force is equal to the time rate of change of momentum.

Newton's third law of motion is simple. It states that action and reaction are equal and opposite. This means that when one body exerts a force on a second body, the second exerts an equal but opposite force on the first. If a man presses his hand against a wall, the wall presses back on the hand with an equal but opposite force. Writers who try to simplify jet propulsion principles often explain everything in terms of the third law, but this is a wrong interpretation. It is possible to explain rocket thrust, which is one form of jet propulsion, according to the third law, but a full explanation of any form of jet propulsion should take into consideration both the second and third laws, and not merely the easier of the two.

THE DISCOVERY OF JET PROPULSION

JET PROPULSION USED TO GUIDE AND DRIVE A BALLOON

The first successful balloon ascension was made by the Montgolfier brothers in France, on June 5, 1783, when their large paper balloon, inflated with smoke and gases from burning straw, climbed to a height of about 1,000 feet.

In the same year, another Frenchman, the Abbé Miollan, designed a balloon that could be guided and driven horizontally by jet propulsion, thus overcoming the objection that a balloon pilot could not control the course of his flight. Unfortunately, the balloon caught fire before the first flight and the Abbé gave up his plans.

JOHN BARBER'S GAS TURBINE

John Barber, an Englishman, received a patent for a gas turbine in 1791. His invention included a method of producing gas, gas and air compressors, a combustion chamber, a turbine wheel, and gearing to reduce the speed in transmitting the driving force to a shaft or spindle. Although this was not a jet propulsion device, it foreshadowed the modern turbo-jet method of aircraft propulsion.

AN EARLY JET-PROPELLED HELICOPTER

In 1903, an artist proposed a method of driving a helicopter by means of steam-jet propulsion, using a rotary engine credited to a man named Avery. Today, we have jet-propelled helicopters, and although they are not driven by steam, we regard them as ultra-modern inventions.

FRANK WHITTLE AND HIS ENGINE

Frank Whittle, in 1928, while a student in the R. A. F. Academy in England, wrote a paper on the gas turbine and one on jet propulsion. In 1930, at the age of 23, he was granted a patent for a turbojet engine. His first jet engine is shown in Fig. 5. During World War II, Whittle was brought to the United States to accelerate our own program of jet research and development. Although the basic principle of jet propulsion has been known for more than two thousand years, today we are only on the threshold of scientific progress that can carry man to the other planets of the universe.

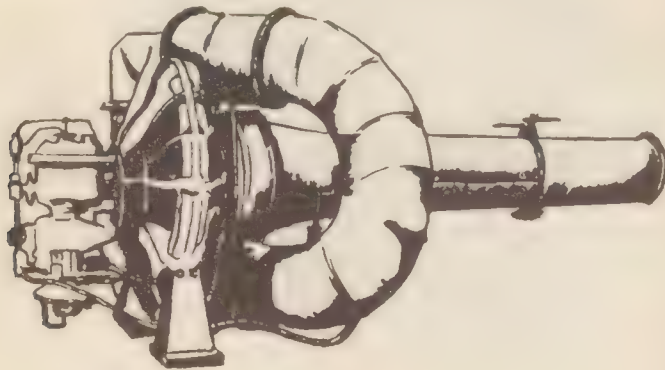


Fig. 5. The first jet engine designed by Frank Whittle.

CHAPTER II

SIMPLE EXAMPLES OF JET PROPULSION

THE TOY BALLOON

An ordinary toy balloon can be used to demonstrate jet propulsion. Blow up the balloon, and then hold its mouth closed with your fingers. The balloon now contains air, which is really a gas, under pressure. The pressure is exerted equally in all directions. It presses with the same amount of force against the top, the bottom, and the sides of the balloon. Since the pressure is equal in all directions, the total propulsive effect is zero.

Remember that the balloon possesses the energy of the compressed air inside it, just as gasoline in an automobile possesses energy that is released when it is ignited by a spark, and in the same manner that a rifle cartridge possesses the energy of the powder in the cartridge case.

Release your grasp of the mouth of the balloon. The balloon leaves the hand and flies across the room, collapses and falls to the floor. During its short flight it has demonstrated the principle of jet propulsion that drives a rocket into the air. Fig. 1 illustrates the application of the law of action and reaction to a balloon.

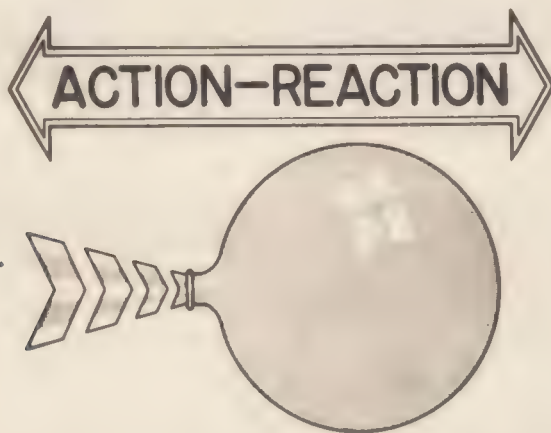


Fig. 1. The application of the law of action and reaction to a balloon.

The pressure against the top of the balloon was equal to the pressure against the bottom of the balloon until the balloon was released by the fingers holding it at the mouth. When released, the compressed air began to escape through the mouth, thus upsetting the balance of pressure between the top and the bottom. The pressure against the top was greater than the pressure against the bottom, hence the balloon, now subjected to unbalanced pressure, moved in the direction of the greater force and continued to move until the pressure inside the balloon

SIMPLE EXAMPLES OF JET PROPULSION

dropped to the pressure of the air outside. When the difference in pressure between the inside and the outside became zero, motion caused by the difference of pressure ceased and the balloon fell to the floor.

The movement of a rocket, whether it uses liquid or solid fuel, is caused by the differences in pressure inside the rocket because a stream of compressed gas is forced out through a small hole.

In its simplest form, any jet-propulsion engine may be regarded as a device for receiving air, adding energy to the air by burning fuel of some kind, and then producing thrust from the accelerated gases generated by the burning of the fuel.

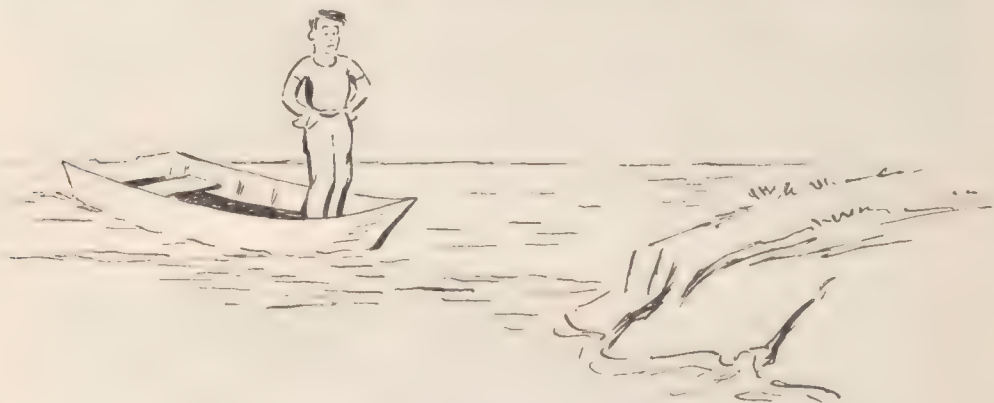


Fig. 2. A boy is standing in the bow of a rowboat which is not in motion.

A BOY AND A BOAT

In Fig. 2, a boy is standing in the bow of a rowboat which is not in motion. In Fig. 3, he has tried to leap from the boat to the shore, but the force with which he has driven himself toward the shore has reacted and pushed the boat backward. He has missed the shore and fallen in the water. If he had stood on a fixed platform which resisted his force when he jumped, he would have reached the shore. Likewise, if he had been familiar with the principle of *reaction*, he would have leaped toward the shore with enough extra force to make up for the backward motion of the boat.



Fig. 3. The boy has tried to leap from the boat to the shore, but the force with which he has driven himself toward the shore has reacted and pushed the boat backward.

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Let us assume that the boy weighs 100 pounds and that when he jumps from the bow of the boat he moves fast enough to carry himself four feet to the shore in one second. Let us also assume that the boat weighs 200 pounds. How far does the boat move backward while he is making the jump?

In high school physics, there is a formula which says that in any action between two objects, the product of the mass and velocity of the first object must equal the product of the mass and velocity of the second, hence $MV = mv$.

Let M represent the weight of the boy and V his velocity. Let m represent the weight of the boat and v its velocity. Then $(100)(4) = (200)(v)$, therefore $v = 400/200 = 2$, hence the velocity of the boat is 2 feet per second. While the boy is jumping toward the shore, the boat moves 2 feet. This disregards the friction between the boy and the air and the friction between the boat and the water. Also, it is an oversimplification of the law of reaction, but it does illustrate reaction well enough to help us to understand jet propulsion.



Fig. 4. As the man throws rocks out of the stern, the boat is driven forward by reaction.

THROWING ROCKS OUT OF A BOAT

In Fig. 4, a man has crossed a lake with a load of rocks in his rowboat but he has lost his oars a few feet from the shore. The boat is still in the water and he is desperately anxious to reach the shore. He throws the rocks as far as he can from the stern of the boat. As he throws each rock, the boat is driven closer to shore, obeying the principle of reaction. When tiny particles of the hot gases produced by burning fuel in a rocket leave the tail at a great speed, they produce the same effect as the man throwing rocks out of the stern of a boat.



Fig. 5. The fan directs a blast of air to the rear and the wagon moves forward.

SIMPLE EXAMPLES OF JET PROPULSION

AN ELECTRIC FAN IN A TOY WAGON

In Fig. 5, a large electric fan has been placed in a clown's cart, facing to the rear. The current comes from a storage battery. The fan directs a blast of air to the rear and the wagon moves forward. Here, too, the principle of reaction is at work to produce the forward motion of a vehicle.

THE GARDEN HOSE

In Fig. 6, the end of a garden hose on the lawn has been driven backward by the reaction of the stream of water leaving the nozzle. If you have ever watched the firemen holding the nozzle of a large fire hose, as they are doing in Fig. 7, you know that it often requires the full strength of two or more men to keep the hose from travelling rapidly to the rear when the powerful stream leaves the nozzle.

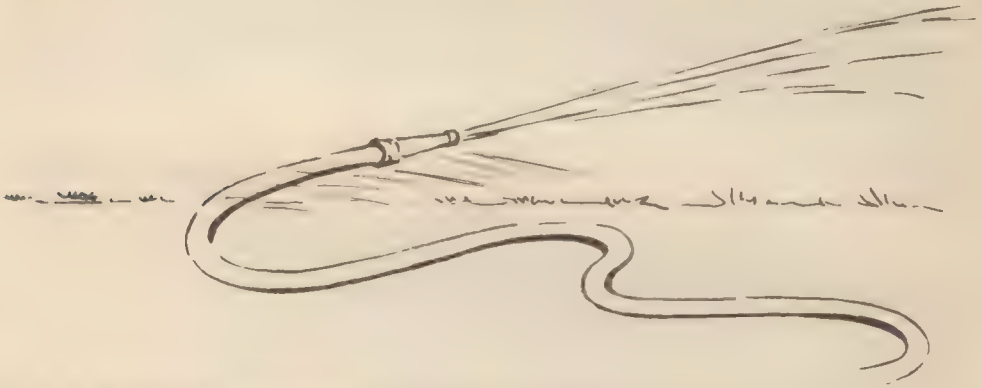


Fig. 6. The end of a garden hose has been driven backward by the reaction of the stream of water leaving the nozzle.



Fig. 7. It requires several men to hold the nozzle of a large fire hose because of the force of reaction.

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THE REACTION OF AIR AND WATER

When a man is swimming, the water reacts against his arms. When he rows a boat, it reacts against his oars. When the blades of a ship's propellers turn in the water, the water reacts against them to make the ship move.

The reaction of the air against the wings of a bird make possible its flight. This is also demonstrated by the reaction of the air against the propellers of an airplane in flight and against the airplane itself.

THE RECOIL OF A GUN

When a pistol, rifle, or shotgun is fired, it recoils ("kicks") in accordance with Newton's third law of motion, which says that action and reaction are equal and opposite, or, to use more familiar language, for every action there is an equal and opposite reaction.

The recoil does not result from the push of the expelled gases on the surrounding air. This is proven by the fact that whether the bullet from a rifle breaks through wood, or flies through the air, or travels through a vacuum, the recoil is the same in each case. If the recoil resulted from the push of the gases on the surrounding air, as many people mistakenly believe, the recoil would vary according to the density of the medium through which the bullet passed. Fig. 8 illustrates the law of action and reaction applied to either a pistol or a jet airplane.

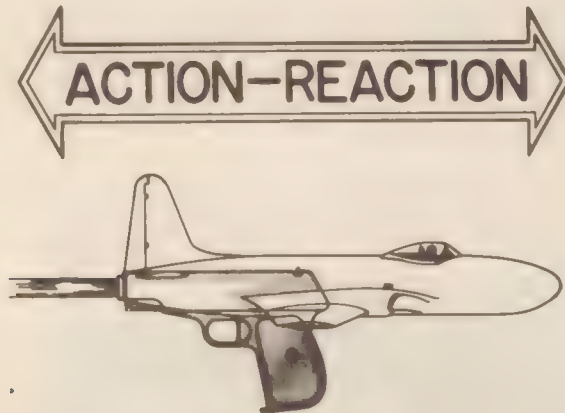


Fig. 8. The law of action and reaction applies to either a pistol or a jet airplane.

Using the same shotgun in each test, the recoil of that particular gun is determined by the muzzle velocity and weight of the shotcharge, wads and powder gases. The recoil increases as the velocity or weight (or both) of the shotcharge is increased. It is a physical impossibility to increase the velocity and weight of the shotcharge of a shotgun load and not increase its recoil if the same gun is used. If a hunter wants to use the same load but obtain less recoil, he must use a heavier shotgun.

When a shotgun shooter fires a heavy load, he presses the butt of his gun tight against his shoulder. He wears a padded coat and may even have a recoil-absorbing rubber pad mounted on the butt of his gun. He does all these things because he knows that the force of the explosion drives the gun backward against his body at the same time that it sends the shot pellets forward through the air.

SIMPLE EXAMPLES OF JET PROPULSION

JET PROPULSION COMPARED WITH GUN RECOIL

If the jet of a jet-propelled airplane is compared with a stream of millions of bullets fired from a group of machine guns mounted close together, then the continuous recoil ("kick") which drives the airplane forward does not obtain its forward force from the jet pushing against the air behind it any more than the recoil of a rifle depends upon the medium through which the bullet passes after it leaves the barrel of the rifle.

FORWARD THRUST DOES NOT DEPEND UPON OUTSIDE ATMOSPHERE

We have already referred to the fact that many people mistakenly believe that the forward thrust of a jet-propelled airplane is obtained by the rush of hot gases from the jet against a cushion of air. We shall now demonstrate that this is an entirely wrong assumption.

Fig. 9 represents a metal sphere filled with ordinary illuminating gas. A sparkplug is mounted in the top and used to ignite the gas. When the spark ignites the gas, there is an explosion with great pressure exerted equally against all points on the inner surface of the sphere. The pressure is equal at all points, hence the explosion does not cause the sphere to move. The pressure on one side of the sphere is balanced or cancelled by the opposite pressure on the other side.



Fig. 9. The pressure is equal at all points, hence the explosion does not cause the sphere to move.

In Fig. 10 we have made a hole labelled "A" in the sphere and once more we ignite the gas inside the sphere by means of the sparkplug. Now there is pressure at all points on the inside of the sphere except at the hole marked "A", where the gases have no opposition and can escape.



Fig. 10. In this case, the sphere moves in the direction of positive pressure, away from the opening.

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All of the forces created by the explosion have been cancelled in the same manner as in Fig. 9, except those forces acting on the inside surface of the sphere at the point marked "B" in Fig. 10, directly opposite the hole marked "A". Here there is positive pressure at "B". At "A", the gases can escape and the pressure is zero. As a result, the sphere moves in the direction of positive pressure, away from the opening. This is simply a matter of internal pressure in the sphere. Nothing outside the sphere has any effect on what happens to the sphere. It will work as well in a vacuum as it will in the earth's atmosphere. This is the principle of jet propulsion.

BALANCED AND UNBALANCED FORCES

Fig. 11 shows a turbojet engine being pulled at both ends of a "dolly" by teams of horses. There is a stalemate because the horses are pulling equally hard from both ends. The dolly is not moved. In Fig. 12, the little boy who has been watching the horses has left his toy wagon and is leading one team of horses. Encouraged by his leadership, this team exerts more strength than the other team and hauls the engine on its dolly in the direction taken by the boy, in spite of the fact that the other team continues to pull. This is a simple example of the fact that while forces are in balance there is no propulsion but when forces are unbalanced a jet engine exerts thrust and moves.

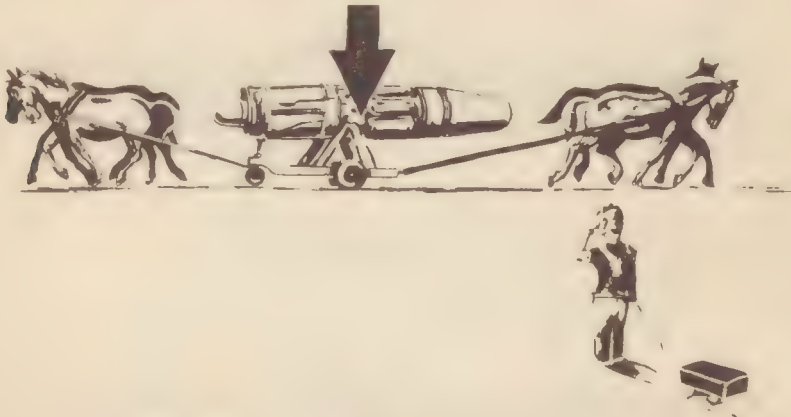


Fig. 11. The horses pull equally from both ends, hence there is no movement of the load.

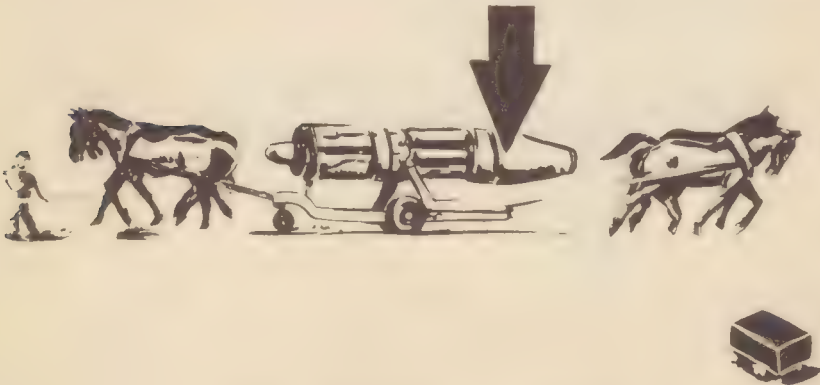


Fig. 12. When forces are unbalanced, there is motion.

SIMPLE EXAMPLES OF JET PROPULSION

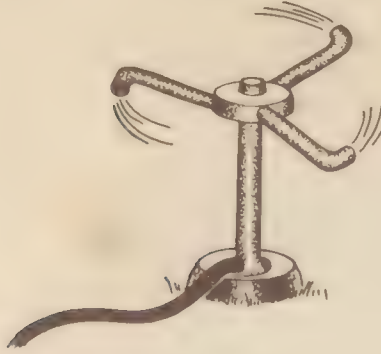


Fig. 13. The modern rotary lawn sprinkler is a version of Hero's aeolipile.

THE ROTARY LAWN SPRINKLER

Fig. 13 shows a modern rotary lawn sprinkler. It is simply another version of Hero's aeolipile. The reaction to the spurting water spins the sprinkler.

Hall L. Hibbard, Vice-President and Chief Engineer of Lockheed Aircraft Corporation, probably had the rotary lawn sprinkler in mind when he gave an address before a special membership luncheon of the Los Angeles Junior Chamber of Commerce in 1945. At that time he said that he thought it might be from 10 to 15 years before a jet propelled helicopter would be developed to the point where it could be used for family travel.

He said that the blast from a combustion chamber would be led up through the rotor instead of out through the tail as it is in the usual jet airplane engine, and that the hot gasses would be exhausted through backswept nozzles at the rotor blade tips. This would establish the same condition of unopposed forces that provide propulsion in other jet devices. The reaction of the pressures would cause the rotor to revolve, just as the rotating lawn sprinkler is driven by the force of the water jets.

The movement of the rotor blades would provide the lift and the forward thrust for this craft. Control would be insured by an auxiliary adjustable jet nozzle in the rear of the aircraft. This helicopter could be operated safely, Hibbard prophesied; and it could be sold for the price of an automobile. The cruising speed would be about 200 miles an hour. Its range would be about 500 miles, and would land and take off with no forward motion whatever. Should engine failure occur, the helicopter could be brought gently to a landing with no power.

Today, jet-propelled helicopters are being flown successfully and although we regard them as modern developments, they operate on the same principle as Hero's aeolipile and the rotary lawn sprinkler.

THRUST-HORSEPOWER RATIO

The driving force of jet powerplants should be expressed in pounds of thrust. The following formula may be used for obtaining the thrust in pounds when the horsepower and the air speed in feet per second are known:

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$$\text{Thrust (pounds)} = \frac{550 \times \text{Horsepower}}{\text{Air speed (feet per second)}}$$

Example: Horsepower is 6,000 and air speed is 750 miles per hour.

Solution: First, change 750 miles per hour to feet per second.

This is practically 1,100 feet per second.

$$\text{Then, Thrust (pounds)} = \frac{550 \times 6,000}{1,100} = 3,000$$

The following formula is used for obtaining the horsepower when the thrust in pounds and the air speed in feet per second are known:

$$\text{Horsepower} = \frac{\text{Thrust (lbs.)} \times \text{Air speed (feet per second)}}{550}$$

Example: Using the same figures as above,

$$\text{Horsepower} = \frac{3,000 \times 1,100}{550} = 6,000$$

A simple statement of the relationship between thrust and horsepower is this: 1 lb. Thrust = 1 Horsepower at an airspeed of 375 miles per hour.

THE SPEED OF SOUND AND THE MACH NUMBERS

The speed of sound is usually taken as 761 miles per hour at sea level. It varies with altitude. At 35,000 feet it is about 660 miles per hour. However, the effects of the sonic barrier, and the problems encountered in flying through it depend upon the ratio of the aircraft speed to the speed of sound, but not on the speed of the airplane in miles per hour.

An Austrian professor named Mach (pronounced mock), who lived in the last century, studied the flight characteristics of projectiles, especially artillery projectiles, and attracted so much attention that his name has been adopted as a means of referring to the speed of sound. Thus, a speed of Mach 1 means the speed of sound, regardless of the altitude. If a pilot flies at Mach .5, he is flying at one-half the speed of sound for that particular altitude. A *subsonic* speed is one having a Mach number less than 1. A *supersonic* speed is a velocity having a Mach number greater than 1. The *transonic zone* is usually defined as a range of Mach numbers from Mach .8 to Mach 1.2, regardless of the speed shown by the airspeed indicator in the airplane.

TYPES OF JET ENGINES

There are two basic types of jet engines, classified as to whether or not they carry their own oxygen: (1) The self-contained or true *rocket* engines which carry both oxygen and fuel; and (2) The *thermal air* engines which must take their oxygen from the surrounding atmosphere.

The thermal air engines may be subdivided again into four current types:

(1) The *athodyd*, or *continuous-firing-duct*, which looks like a long barrel with both heads missing. The fuel is fed through a ring of holes ahead of the middle of the long barrel or tube. The incoming air, compressed by ram action, is expanded after being mixed with fuel and burned.

SIMPLE EXAMPLES OF JET PROPULSION

(2) The *pulsejet*, or *intermittent-firing-duct*, used to power the German "buzz-bomb" in World War II. As the airplane travels swiftly through the atmosphere, compression waves are forced into the combustion chamber. The waves are controlled by a series of shutters or flaps in the duct inlet. These shutters are forced open by the ramming action of the incoming air and closed when the pressure builds up inside, opening and closing intermittently. The fuel injection is continuous, but the combustion is intermittently fired by an electric spark at a rate of about 40 times per second in some models.

(3) The *turbojet*, or *gas-turbine jet engine*, a clever combination of the open-cycle gas-turbine with the athodyd (continuous-firing-duct). An air compressor is mounted well forward, ahead of the combustion chamber. A one- or two-stage turbine is at the rear of the combustion chamber and mounted on the same shaft as the compressor. The turbine absorbs only enough of the energy of the rearward rushing gases of combustion to operate the compressor and the accessories; the remaining energy has high velocity, exhausts to the rear, and provides thrust. The sole function of the turbine is to turn the compressor; it does not contribute in any other manner to the production of thrust.

A one-stage turbine is often called a single-stage turbine and a two-stage turbine is frequently referred to as a multi-stage turbine.

(4) The *turboprop*, classified as a variation of the turbojet because it is a combination powerplant using the power generated by the gas turbine to rotate a conventional propeller. At the same time, the basic jet engine provides thrust by exhausting its hot gases to the rear.

There are various *combination jet powerplants*, such as a combination of two types of jet engines, or a combination of a jet engine with a conventional piston-type, reciprocating engine driving a propeller.

A *compound engine* is an engine which derives its total useful power from two or more power producing units. An example is the Turbo Compound engine manufactured by the Wright Aeronautical Division of the Curtiss-Wright Corporation. It is a standard piston engine plus three small jet turbines in the exhaust system which recover 20 percent more power than the basic piston engine produces. This is based upon *power recovery*, which is a name for a method by which the heat energy in the exhaust of an engine can be converted into useful work.

We have examined the historical background of jet engines and studied the application of the jet principle to various familiar situations. In the following chapters we shall study each of the types and its application to flight propulsion, one at a time.

THE ATHODYD

THE RAMMED-AIR ENGINES

There are two types of jet powerplants that utilize the principle of "*rammed-air*" for their operation. These are: (1) The *athodyd*, technically called a *continuous thermal duct*, and popularly referred to as "the flying stovepipe" because of its simplicity, and (2) The *pulsejet*, technically referred to as the *resonant jet*, and sometimes described as an *intermittent-firing duct powerplant*. Whenever the single word "*ramjet*" is used to describe one of these rammed-air jet engines, the reference is to the "*athodyd*" type of powerplant.

THE ATHODYD (OR RAMJET)

The word *athodyd* was coined by contracting four words: Aero-THERmo-DYnamic-Duct. It is simply a tube with open ends slightly restricted. Its thrust is developed by the continuous burning of fuel within the tube, but cannot start itself. It must have some initial source of propulsion to obtain enough velocity for starting.

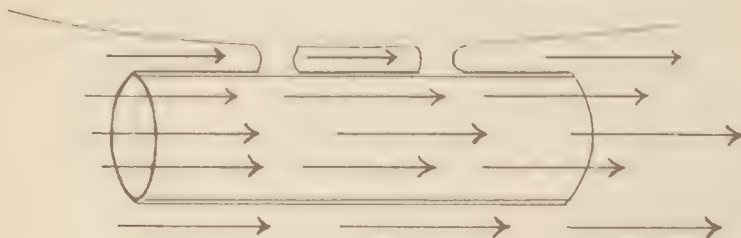


Fig. 1. A metal cylinder open at both ends and attached to the bottom of an airplane.

In order to understand its operation, we shall begin by constructing a thermal duct. A *duct* is simply a tube or canal through which a fluid or other substances can pass. Fig. 1 shows a metal cylinder open at both ends and attached longitudinally to the bottom of an airplane. Air enters the duct at the front and leaves at the rear. The air loses some energy from skin friction and the disturbance of the flow at both the entrance and the exit. There is no gain in velocity. Actually, there is some loss of velocity.

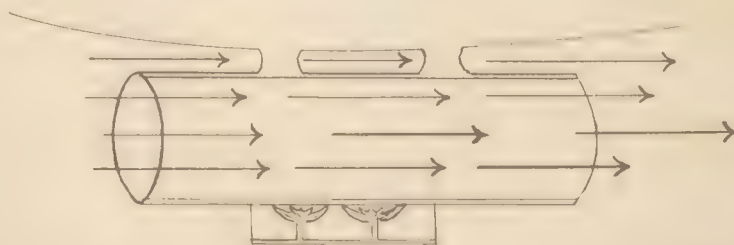


Fig. 2. Burners have been added to raise the temperature of the air passing through the cylinder.

THE ATHODYD

In Fig. 2, we have supplied two external burners to heat the duct. This will raise the temperature of the air passing through the duct. When the air is heated, it expands and gains velocity so that it moves faster as it leaves than it did when it entered.

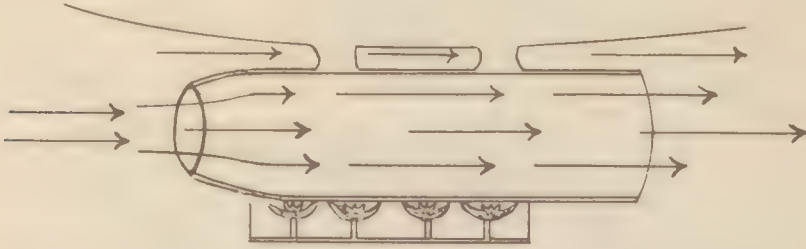


Fig. 3. More burners have been added. The entrance to the cylinder now has a divergent nozzle.

In Fig. 3, we have increased the amount of heat by burning more fuel. This is represented in the illustration by the addition of two burners. The velocity of the air is increased by the additional heat but we know that the amount of heat that can be added is largely dependent upon the pressure of the air. Therefore, we have changed the shape of the entrance to the duct so that it is now a *divergent* nozzle, that is, it spreads out toward the rear of the duct. Unfortunately, a divergent entrance nozzle reduces the velocity of the air, hence we have suffered a loss by the same means that provided a gain.

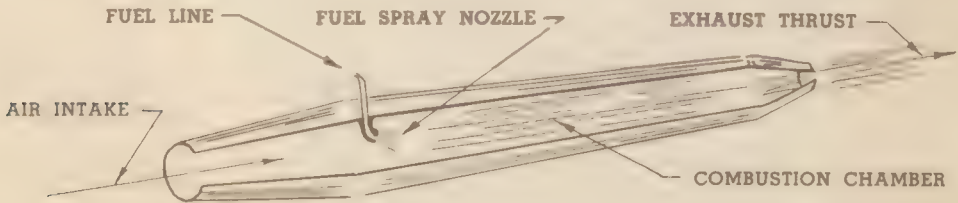


Fig. 4. The cylinder now has a convergent exit nozzle, the external burners have been removed, and the air is heated by means of a spray nozzle at the end of a fuel line. We now have an athodyd.

In Fig. 4, the duct has been given a *convergent* exit nozzle, that is, it is smaller toward the rear. This increases the velocity of the air because a convergent exit nozzle has an effect opposite to that of a divergent entrance nozzle. However, the convergent exit nozzle reduces the air pressure. The amount of heat which can be added to the air is obviously limited. A considerable amount of heat is wasted on the atmosphere by our exterior heating system. The unit we have designed is, in theory, an elementary jet propulsion device but its efficiency is too low to drive an airplane.

JET AIRCRAFT SIMPLIFIED

In Fig. 4, we have discarded the external burners and provided a fuel line leading to a spray nozzle inside the duct where the fuel is burned to provide direct heat to the stream of air. We now have an athodyd. Air enters the duct at the front under the pressure caused by forward movement through the atmosphere, it is combined with fuel and ignited, and it creates a jet thrust as it leaves the exit. Except for the possible use of fuel pumps in some advanced design, or the use of other accessories, the athodyd has no moving parts.

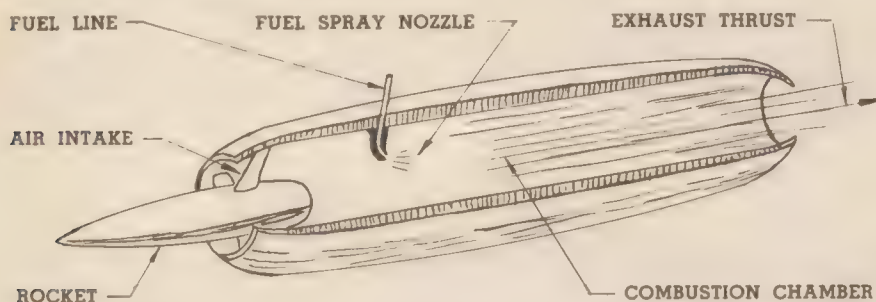


Fig. 5. A rocket has been placed in the noze of the athodyd for starting.

A ROCKET ATHODYD

Since the athodyd must have some initial source of propulsion to obtain enough velocity for starting, we have placed a rocket in its nose in Fig. 5. This rocket is used only to start the unit. The rocket shoots forward and pulls the unit through the air, thus forcing the air to pass through the air intake. In the combustion chamber, fuel enters through a spray nozzle, the mixture of fuel and air is ignited, an explosion takes place, and this causes the unit to move forward. By the time that the athodyd is acting as a propulsion unit, the rocket has disintegrated. It should be apparent that we have proposed this method of starting an athodyd for purposes of explanation only.

The operation of the athodyd at speeds below that of sound appears to be impractical today. The problem of bringing it to the high speeds necessary for efficient operation may possibly be solved by using some auxiliary power, such as rockets. Its great speed and the limitations on its operation in its present state of development indicate that its greatest usefulness today is for pilotless aircraft or guided missiles, and also for supersonic aircraft.

THE LEDUC ATHODYD

René Leduc, a French engineer, exhibited a model of an airplane powered by an athodyd at the Paris Salon de l'Aviation, in 1938. Fig. 6 shows the side and front-end views of his model. The whole fuselage from nose to tail forms a continuous air duct. It has a divergent air-intake to compress the air and a divergent air-exit to expand the air. The forward speed of the airplane causes air to be rammed into the intake. The velocity drops because of the divergent shape and the pressure is increased. Liquid fuel is preheated in tanks and injected into the combustion chamber through a large number of spray nozzles. It is there mixed with air and burned. The hot gases of combustion then leave through a narrowed tube in the rear of the airplane at reduced pressure and increased velocity to provide forward thrust.

THE ATHODYD

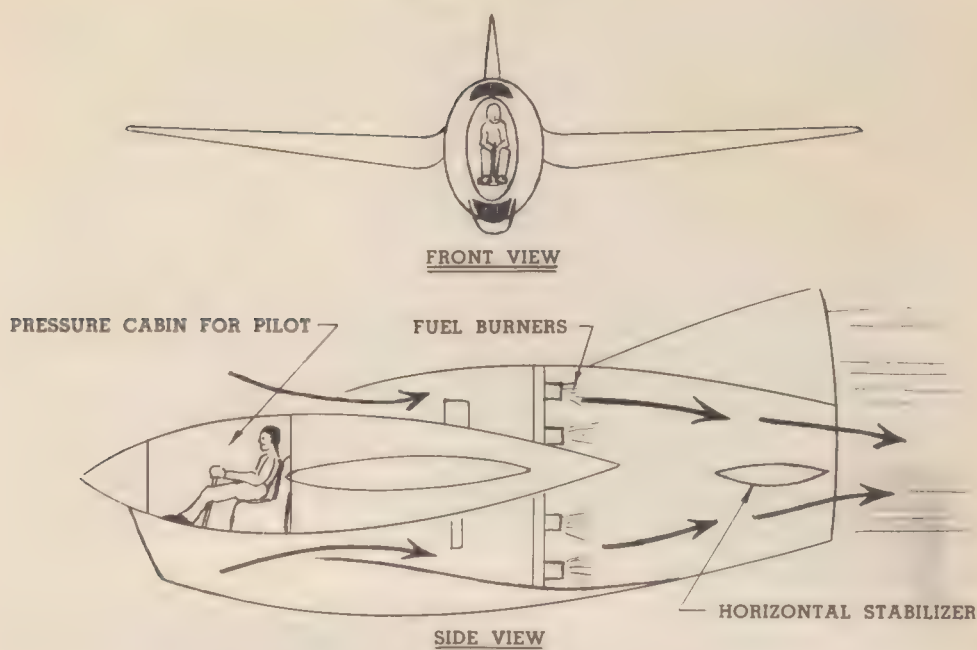


Fig. 6. The side and front-end views of the Leduc athodyd.

Leduc also considered the fact that burning in the usual sense of the term is not complete if the combustion chamber temperature is too high and the velocity of the airstream too great. He provided a series of small tubes which carried air from the combustion chamber and recirculated it along its walls in order to reduce the pressure and velocity of the air next to the walls. The purpose of this feature was to prevent the formation of what the engineers call a "boundary layer" and thereby improve combustion.

The 1953 version, which is sponsored by the French Air Ministry, is designated as the Leduc 021. It weighs 11,000 lbs. and is designed for a speed of Mach 0.95 in level flight (approx. 710 miles per hour at sea level).

THE ROCKET-ATHODYD OF G. GEOFFREY SMITH

In October, 1943, G. Geoffrey Smith, an English author and engineer, submitted to the British Government plans for a long-range weapon which combined the athodyd with rocket propulsion for the bombardment of Germany from bases in England. He proposed that the missile be launched by means of a catapult, a high-trajectory mortar, or some form of rocket gun.

Rockets were to be arranged around the exit nozzle at the tail and fired in succession in order to get the missile launched and high enough into the air for the athodyd to take over the propulsion efficiently. Thereafter, the athodyd would be the sole source of power. His athodyd was to resemble the Leduc design previously described. Fins on the tail would provide for stabilization. The directional control was to have been accomplished by either an automatic pilot or radio. The range was to have been controlled by providing the correct ratio of fuel to the explosive load to get the missile to the target.

JET AIRCRAFT SIMPLIFIED

DUCTED RADIATORS

The divergent-convergent duct of the athodyd has applications in aircraft design other than for propulsion. For example, the radiators of certain liquid-cooled engines were within the slipstream of the propeller and contributed to the total drag of the airplane. When the radiators were mounted within divergent-convergent ducts, the stream of air was warmed, its speed was increased, and the jet effect thus produced overcame the drag contributed by the radiator.

FORMAL DEFINITION

Having considered several aspects of the athodyd, we can now produce a formal definition: An *athodyd* is a divergent-convergent tube equipped with fuel burners which obtains its compression from forward motion or ram pressure, the hot gases being exhausted at a higher velocity than that of the entering air, thus producing a reaction force for propulsion.

IGNITION

The mixture of fuel and air is originally ignited electrically. This can be accomplished through the use of an electric glow plug which operates on the same principle as the cigar lighter in an automobile, although in appearance it more closely resembles a conventional aircraft spark plug. Once lighted, the heat in the combustion chamber is great enough to continually ignite the fuel-air mixture, thus providing the continuous combustion which is an essential feature of this type of powerplant.

NO LUBRICATION

The athodyd has no moving parts in its pure form, hence it does not need a lubrication system. This saves weight and reduces manufacturing, maintenance and overhaul problems.

FUEL FOR THE ATHODYD

In theory, all jet engines can use any fuel that can be blown through a spray nozzle and will burn in air, but the petroleum engineers are developing special fuels for jet powerplants and find that the athodyd presents special problems.

In the past, the athodyd fuels have been principally gasoline and kerosene. These are classified as *hydrocarbons* because they are chemical compounds containing hydrogen and carbon only. Acetylene and benzene are other examples of hydrocarbons.

The hydrocarbons will ignite in the turbulent flow of the athodyd in velocities ranging from about 250 to 700 feet per second. Above these velocities, there is a tendency for some hydrocarbons to blow out, that is, the burning ceases and the pilot soon has a dead engine instead of a roaring blowtorch. Certain substances which are not hydrocarbons will not blow out at velocities of 700 feet per second or more.

The air-fuel ratio is important in the athodyd. Using hydrocarbons, the overall air-fuel ratio is from 12:1 to 30-35:1. In other words, there may be 12 parts air by weight to 1 part fuel by weight at one end of the air-fuel range, and from 30 to 35 parts air by weight to 1 part fuel by weight at the other extreme. About 16:1 is generally regarded as the best combustion ratio at present, although it can be gotten down to 12:1 if a richer mixture is desired. However,

THE ATHODYD

the burning may be "patchy" at the latter ratio. Some of the fuels outside the hydrocarbon family will burn well with a ratio as rich as 6-7:1 and as lean as 50:1, thus providing more flexibility in the choice of air-fuel mixture.

MODERN DEVELOPMENT OF ATHODYDS A BY-PRODUCT OF TURBOJET

Although the design of the athodyd is much simpler than that of any of the other jet engines, with the possible exception of the rocket, much of its practical modern development has come as a by-product of turbojet research. The engineers working on turbojets found that when their engines reached speeds above 500 miles an hour in flight, the air was ramming through the engine so fast that neither the turbine nor the air compressor was required. Actually, higher speeds could be obtained if the turbine and air compressor were omitted. These units were needed only to get enough air into the combustion chamber at the low speeds used in take-off to put the engine into operation.

When this fact was discovered, the exhaust tailpipe of an airplane was modified enough to provide for the burning of fuel within the pipe and the use of a rocket as a launching device. The whole object weighed about 70 pounds and had no moving parts. When the tailpipe reached a high enough velocity in flight, the air entering the nose was compressed by its own speed, the fuel was burned with this self-compressed air, and the exhaust went out the rear of the pipe with enough force to drive the tailpipe through the air at a speed of 1,500 miles per hour.

The engineers calculated that at this velocity, the tailpipe functioned as an engine developing a thrust equivalent to 3,000 horsepower. This is an enormous amount of power to be developed by a device weighing only 70 pounds. The essential functions of compression, combustion and exhaust were accomplished with a minimum amount of parts and time. The only big objection is that this "flying stovepipe with a fire inside" must have a high velocity before it can begin to deliver thrust.

THE MC DONNELL ATHODYD HELICOPTER

Fig. 7 shows the U.S.A.F. XH-20 athodyd (ramjet) helicopter made by McDonnell Aircraft Corporation, St. Louis 3, Missouri, and popularly known as the "Little Henry". This is really a flying test stand for the development of athodyd engines and athodyd-powered helicopters in general. The usual crew is one man, although it has carried two. The official first-flight day was May 5, 1947. It is commonly regarded as the first successful helicopter powered by an engine of the rammed-air family. Basically, it is a three-dimensional aerial motor-cycle consisting of a two-blade rotor, two tip ramjets, a small rudder, and an open steel-tube structure supporting the pilot, fuel tanks, and controls.

Different size rotors have been used. The usual diameter (length) is either 18 feet 5 inches or 20 feet. Two McDonnell-developed athodyd units weighing only ten pounds each are attached to the ends of the two all-metal rotor blades which are actuated by conventional-appearing pilot controls. Since the power is applied directly to the blade tips, heavy engine parts, gear systems, and transmissions are eliminated. Maintenance problems are simplified, and the weight is greatly reduced. With the rotor spindle merely serving as the means of attaching

JET AIRCRAFT SIMPLIFIED



Fig. 7. An athodyd helicopter ready for a test flight.

the rotor to the structure, the control is direct and the usual complex "swash-plate" system is eliminated. The blade tips do not develop torque, hence an auxiliary tail rotor is not needed. All of these simplifications add up to a further saving in weight — the old nemesis of helicopter design.

The workable, light-weight engine was developed by McDonnell engineers after more than three years of research and experimentation. Early flight tests were conducted with propane as a fuel. Gasoline burning jets are now used, and the first demonstration of their use took place in October, 1948. The use of 80-octane gasoline will eliminate the necessity of carrying special fuel into areas where the craft will be in operation because of the use of automobile-grade fuel.

Although the fuel consumption of engines of the ramjet family has always been a major problem, several refinements make this craft suitable for operational use. Two tanks are attached to the helicopter assembly and supply fuel through lines into the blades. After the initial fuel pressure is built up, centrifugal force provides the necessary pumping action to keep the fuel system in operation.

Helicopters powered with ram-jet engines (athodyd and pulsejet) can be started with electric motors driven from storage batteries and then brought to an adequate operating speed without the use of external power of any type. This is an exception to other statements in this text regarding the problems encountered with jet propulsion in conventional aircraft.

The military advantages of a ramjet helicopter are almost obvious. Ground force commanders could dispatch craft of this type quickly without reliance on a

THE ATHODYD

staff of highly trained pilots. Larger models could provide speedy transportation for bulky ground-force equipment to otherwise inaccessible areas. Commercial models can be developed to include "shuttle hops" between air terminals and civic centers, and to lifting heavy loads to otherwise unreachable areas.

The weight of the current Little Henry is 280 pounds empty and it has a gross weight of 620 pounds. The forward speed is up to 50 miles per hour. The helicopter is only 12½ feet long, 5 feet wide, and 7 feet high.



Fig. 8. The original single place Hiller-Hornet.

HILLER-HORNET

Another of the ramjet (or athodyd) type helicopters that has shown great promise is the Hiller-Hornet. The original design was a single place job as shown in Fig. 8. However, the modification that currently is being produced for the Armed Forces is a two placed helicopter, with ramjet tip-powered rotor blades. Specific design information and performance figures are military secrets, but this new Hiller-Hornet, designated as the HJ-1, is being utilized by the Armed Forces for military evaluation purposes.

MARQUARDT AIRCRAFT RAMJET'S

The Marquardt Aircraft Co., Van Nuys, California, has also manufactured and experimented with various types of ramjet (or athodyd) engines. Although the majority of Marquardt's current projects are classified as "restricted", the

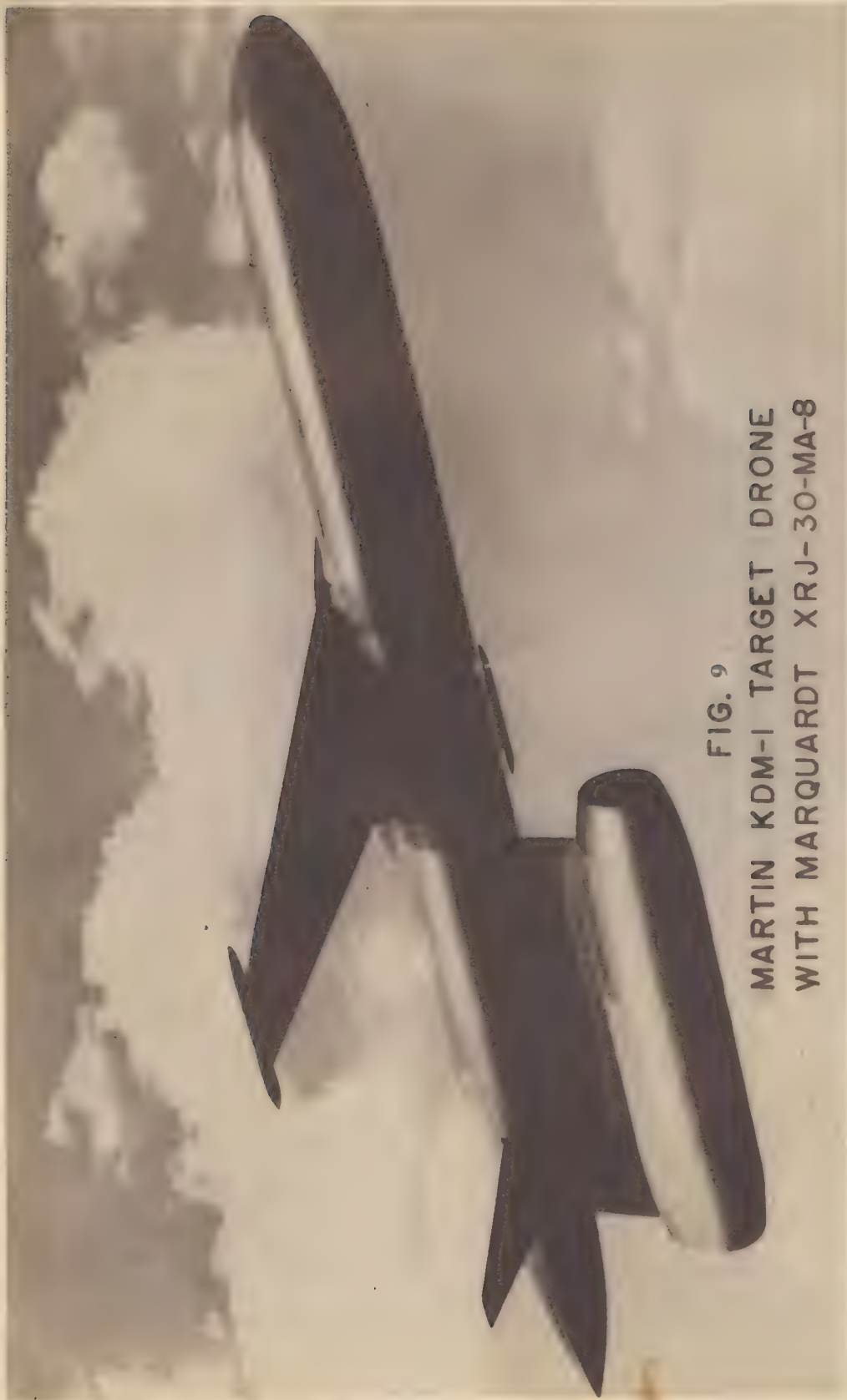


FIG. 9
MARTIN KDM-1 TARGET DRONE
WITH MARQUARDT XRJ-30-MA-8

THE ATHODYD

following three pictures give evidence of the "Buck Rogers" types of problems their engineers are tackling. Fig. 9 is the Glenn L. Martin Aircraft Company's KDM-1 "Target Drone" which is a pilotless craft that is powered by a Marquardt XRJ-30-MA-8 ramjet engine. Fig. 10 on the other hand illustrates what is believed to be the first solely ramjet-powered flight of a man-carrying aircraft. With two Marquardt Model C-30 thirty-inch diameter ramjets on its wingtips, a Lockheed F-80 "Shooting Star" was maintained in level flight at maximum top speed with the airplane's main powerplant turned completely off.

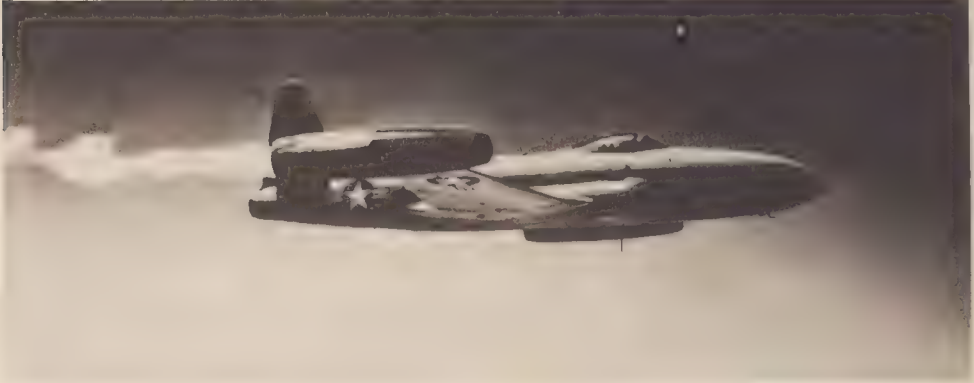


Fig. 10. Lockheed F-80 "Shooting Star" powered by only two Marquardt ramjets.

Both of the ramjet engines shown in Fig. 9 and Fig. 10 are of the *subsonic* type — that is, they are designed to operate below the speed of sound, which is about 750 miles per hour at sea level. These subsonic ramjet motors have their front ends completely open, as illustrated in Fig. 11. However, as these engines travel above the speed of sound — that is, as they travel in the supersonic range —

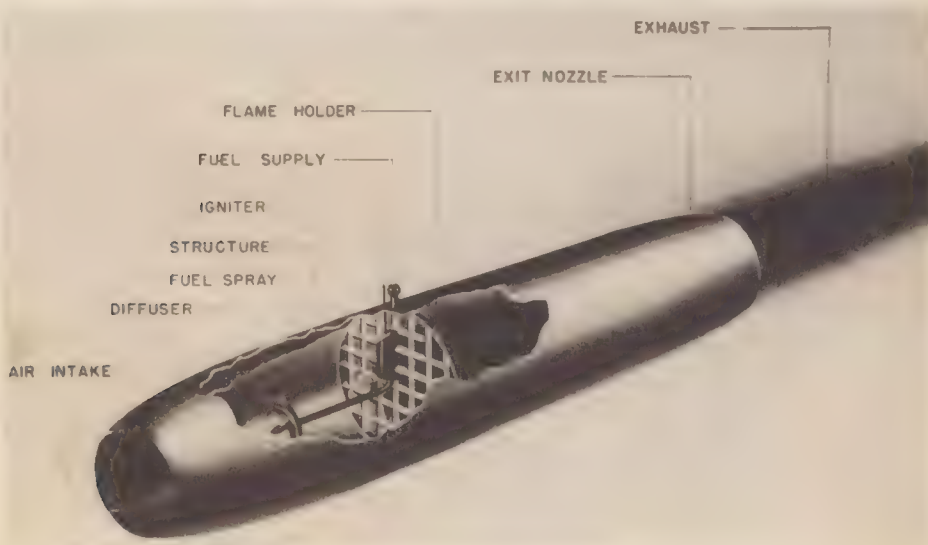


Fig. 11. Typical subsonic ramjet (or athodyd) powerplant.

JET AIRCRAFT SIMPLIFIED

it is necessary to break the shock wave that builds up in front of the engine. Thus it is that the engineers have added a long needle-like nose piece to the design of these *supersonic ramjets* as can be seen in Fig. 12. These long nose pieces are extended back into the shell to enclose what is called the "inner can" or "inner can" of the engine.

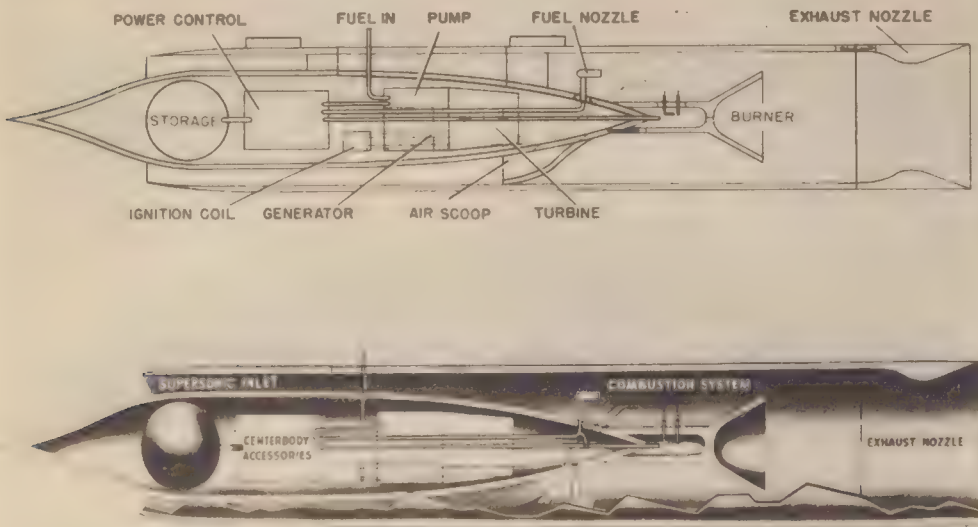


Fig. 12. Typical supersonic ramjet (or athodyd) powerplant.

SUMMARY OF ATHODYD CHARACTERISTICS

Use: Pilotless aircraft, guided missiles, helicopters, and auxiliary powerplants to take over when other sources of power have reached sufficient velocity.

Maximum Speed Range: Probably from 800 to 2,600 miles per hour.

Advantages: Simple design and great speed.

Disadvantages: In present state of development, requires another type of powerplant to bring main powerplant to operational speed except in case of helicopters.

CHAPTER IV

THE PULSEJET

THE PULSEJET PRINCIPLE

It is important to clearly understand that the *pulsejet*, technically referred to as a *resonant jet*, and sometimes described as an *intermittent-firing duct powerplant*, also known as an *aeroresonator*, is different from the athodyd (or ramjet) that is described in chapter three. Although in the past, the pulsejet has sometimes been called a ramjet type of engine, in modern usage it is more correct to restrict the term *ramjet* to the *continuous firing duct* (or athodyd) as described in the last chapter, and restrict the term *pulsejet* to the *intermittent-firing duct* that is described in this chapter.

BASIC FEATURES

The *pulsejet* is a long tube (duct) equipped at the forward end with a grating-type valve which consists of a number of shutters. Fuel ignited behind this valve develops a pressure that closes the valve and in turn creates a jet effect at the rear end. The pressure inside is reduced, this opens the valve, and a fresh charge of air is admitted through the shutters for the next ignition. The valve thus operates by a series of changes of pressure and is the only moving part of this powerplant.

Fig. 1 is a simplified drawing of the pulsejet showing the valve, a fuel nozzle, and the combustion chamber. Fig. 2 shows the air intake and the shutters in the

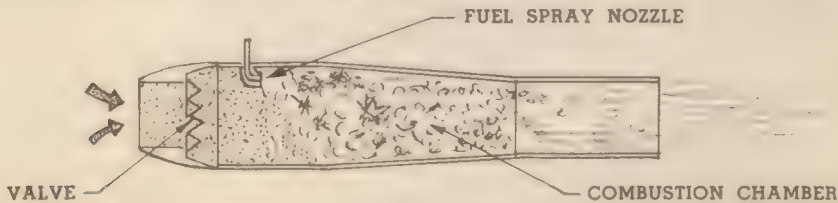


Fig. 1. A simplified drawing of a pulsejet.

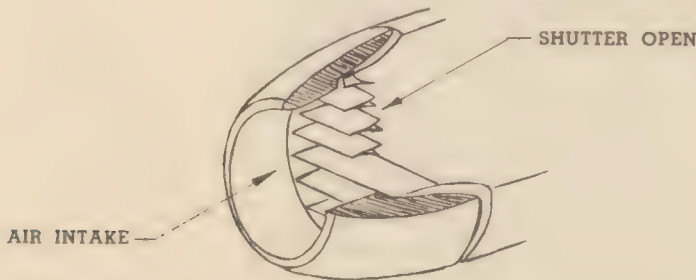


Fig. 2. The air intake and shutters are in the open position.

JET AIRCRAFT SIMPLIFIED

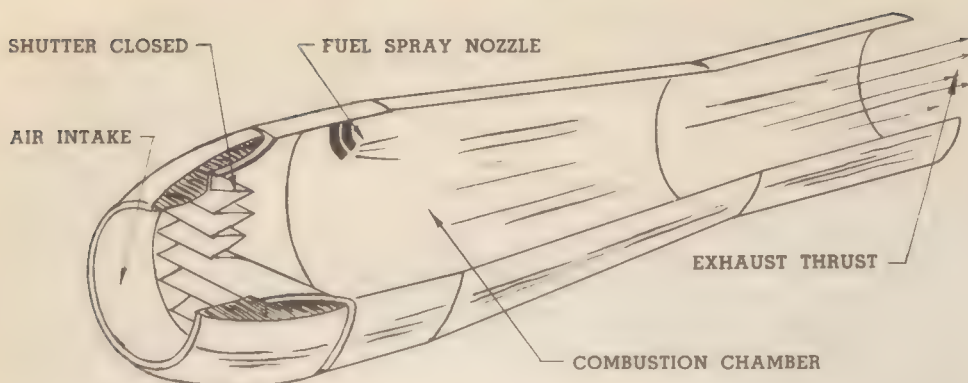


Fig. 3. The air intake, fuel spray nozzle, combustion chamber, and exhaust while the shutters are in the closed position.

open position. Fig. 3 shows the air intake, the fuel spray nozzle, the combustion chamber, and the exhaust while the shutters are in the closed position. Fig. 4 illustrates the important features of the pulsejet with the shutters open and differs from the other drawings principally because of the fact that it shows a transition section with a pronounced taper between the combustion chamber and the tailpipe proper.

The fuel spray nozzles are located directly behind the air valve. The spark-plug for providing initial ignition is located farther back in the combustion chamber.

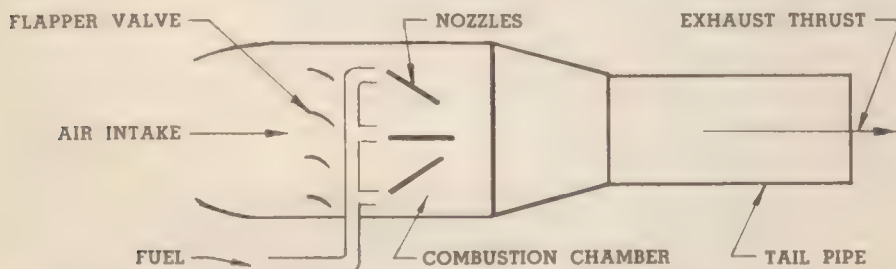


Fig. 4. The important features of the pulsejet are shown with the shutters open. In this drawing, the transition section is clearly shown to have a pronounced taper between the combustion chamber and the tailpipe.

OPERATION

The high pressures are developed by means of periodic explosions, that is, the explosions take place at fixed intervals. The frequency of the actuating cycle depends upon the design of the duct (tube) and may be extremely high. For example, the pulsejet of the German V-1 "buzz-bomb" had a frequency of about 2,800 cycles per minute.

The pulsejet, considering the whole powerplant, has its own wave frequency. In order to obtain the greatest efficiency, the explosions of the fuel-air mixture must be in *resonance* with the compression-wave frequency of the whole system. In other words, they must vibrate in sympathy with one another. This explains the terms *resonant jet* and *aeroresonator*.

THE PULSEJET

The pulsejet in its present state of development vibrates greatly and makes an ear-shattering noise. The pulsating noise made by the exhaust is *intermittent*, rather than continuous, because the combustion which takes place after the first ignition of the fuel-air mixture by the single spark plug is not continuous. This operating characteristic gave the pulsejet its popular name of "stuttering stove-pipe."

In operation, the air is drawn in from the outside atmosphere, mixed with fuel, compressed in the next stage by the compression wave caused by the previous explosion of a fuel-air mixture, the new fuel-air mixture is ignited, combustion takes place, and then the gases of combustion are exhausted to the rear. All of these events take place at high pressure and temperature.

OPERATING STAGES

Analyzing the events which take place in the pulsejet, it is apparent that there are three phases or stages, namely: (1) The charging stage, (2) The combustion or explosion stage, and (3) The replenishing or refilling stage.

The aircraft must be moving fast enough for the outside air to be rammed into the air intake in order that the *charging stage* may take place. During this stage, the air rammed into the duct has enough force to build up a positive pressure in the diffuser section, causing the shutters or flaps of the valve to open. The compressed air flows into the combustion chamber where it mixes with the sprayed fuel.

The sparkplug is used for ignition only when the pulsejet is first started. Thereafter, the *combustion or explosion stage* is begun by the heat of the walls of the combustion chamber setting fire to the fuel-air mixture. The explosion brought about by the combustion (burning) increases the pressure and causes the shutters of the air-intake valve to close. The combustion gases leave the rear of the duct with so much violence that they produce the reactive force or thrust that drives the aircraft forward through the air.

After the gases of combustion have been exhausted to the rear, the pressure of the air in the combustion chamber becomes lower than the pressure of the air in the atmosphere outside the powerplant. This reduction of pressure causes the air-intake valve shutters to open, since the pressure of the outside air is greater than the inside air. This is the *replenishing or refilling stage*. A new charge of outside air is rammed into the air intake and the operating cycle repeats itself.

Considering these three stages of operation as one cycle, if there are 50 cycles per second, there are 50×60 or 3,000 cycles per minute. This is roughly the frequency of the German V-1 "buzz-bomb" previously mentioned.

FUEL AND COMBUSTION PROBLEMS

It should be observed that there is no positive and direct method of controlling the compression of the air required to support the combustion of the fuel-air mixture, and also that the combustion in the pulsejet is intermittent. These two features are found in other types of jet powerplants but they nevertheless detract from the overall operating efficiency. In the case of the pulsejet, they are offset by the favorable factors of simplicity of design, comparative low cost of manufacture, and low weight in ratio to the thrust developed.

JET AIRCRAFT SIMPLIFIED

Like the turbojet and the athodyd, the pulsejet must have what is called *flame stability*, that is, the burning must be steady or disaster may take place. The temperatures are higher and the pressures more varied in the athodyd and the pulsejet than in the turbojet, but in all three types there must be efficient combustion over extreme ranges of pressure and temperature.

In both of the ramjet types, the fuel characteristics offer problems which are more difficult than in the turbojet. The design of the combustion chamber, the extent of the atomization of the fuel spray, and the volatility of the fuel can be controlled by the design engineers, but no one can exercise much control of the combustion pressure.

The inlet temperature of the combustion zone cannot be predicted, the velocity of the air stream entering the combustion zone is equally whimsical, and yet both of these have an effect on the stability of the flame.

Characteristics of fuel which are especially desirable for both the pulsejet and the athodyd are: A low freezing point, very high rates of flame propagation, high combustion temperatures, and a low rate of deposit of products of combustion on the walls of the combustion chamber.

Everything which we have said about the use of gasoline, kerosene and other "hydrocarbon" fuels in the chapter on the athodyd applies to a considerable extent to the pulsejet, hence entirely new fuels may be developed and found more efficient than those known now.

Comparing the two ramjet types with the turbojet, but limiting the discussion to combustion, the fuel problems are somewhat similar, but the properties of hydrocarbon fuels have less effect on combustion in the ramjet powerplants than they do in the turbojet, although the problems presented by velocity and other variables are much the same.

In the pulsejet, certain fuels have an adverse effect on the shutters of the air-intake valve. Fuels in which oxygen is compounded are found to produce more thrust.

Engineers are now working to improve the design of the air-intake valve, they are considering the use of intermittent instead of the present continuous injection of fuel, and they are also attempting to improve the ignition process to make it more positive in operation.

FUEL CONSUMPTION AND SPEED

Jet propulsion is merely another method of making an airplane go forward. The jet engine is not as efficient as the conventional reciprocating-engine-and-propeller combination in many respects. For one thing, it requires more fuel to produce the same power for all of the present jet engines and this is particularly true of the ramjet family. This matter of fuel consumption will no doubt be improved in the future as more work is done in research on materials and design, particularly materials which can withstand the tremendously high temperatures.

The efficiency of propulsion, or in other words, the effectiveness of the reactive force that drives the airplane, depends on the speed of the jet aircraft. The efficiency improves as the aircraft moves faster, and is greatest as the speed of the aircraft approaches the speed with which the exhaust gases leave the tailpipe. However, in taking off and at low speeds the efficiency is low.

THE PULSEJET

There are several advantages that make jet propulsion worth while. A jet engine does not require high octane gasoline; it can use kerosene or some other fuel. Since there is no propeller a very short or low landing gear may be used on the airplane. Then, too, the simplicity of design is reflected in savings of material and manufacturing time, both of which are factors not only of economy but also of national defense in an emergency.

All of the foregoing are incidental reasons. The most important reason for favoring jet propulsion is *speed*. A jet propulsion aircraft can travel at speeds impossible for propeller-driven airplanes.

The reason why jet propelled aircraft can travel so very fast goes back to the fundamental principles we discussed in the earlier chapters. It concerns the peculiar things which take place when an object moves through the air at a speed greater than the speed of sound. At this point we shall not explore all the scientific ramifications, but shall say that when an object moves through air at a speed faster than that of sound, the air does not act as it does at lower speeds. It does not flow around the object in the manner it does at the lower speeds. It piles up in front of the moving object like a wave piles up in front of a boat in the water. We call this a problem of "air compressibility."

When a wave piles up in front of the bow of a boat, it can rise into the air, but when air piles up in front of a moving object there is no place to go; it must be pushed ahead of the object. All this means that a great increase of power is required to drive the object forward.

The trouble starts long before the speed of sound is reached. The flow of air over certain portions of an airplane is irregular and is speeded up. The propeller, which is rotating and at the same time moving forward, may be driving the airplane at a speed of only 400 miles an hour and yet the tips of the propeller blades may be travelling faster than the speed of sound. Dispensing with a propeller is one step in getting more top speed, hence the jet powerplant comes into its own where speed is of vital importance.

The advantages of jet propulsion, especially ramjet propulsion, are especially noticeable at very high altitudes. The speed of sound is less at high altitudes because of the extreme cold and the lower air density. These factors limit the propeller still more and make it almost impossible to keep the power of the conventional reciprocating-engine-propeller combination from dropping off rapidly.

This analysis leads to the conclusion that jet propulsion is especially suited to high speed and high altitude flying.

THE GERMAN V-1 "BUZZ-BOMB"

The first known practical application of pulsejet propulsion was in the German V-1, or "buzz-bomb", of World War II. It existed in several forms but Fig. 5 illustrates the usual design. This was a pilotless, robot controlled aircraft, built like a miniature airplane. In one form, the wing span was 17½ feet, the wings were two feet eight inches from leading edge to trailing edge, and the fuselage was 21 feet, 10 inches long. A steel fuselage housed a bomb weighing more than a ton, the fuel tank and the control mechanisms. A pulsejet unit was mounted above the fuselage and to the rear, as shown in Fig. 5, and extended over the tail of the aircraft proper enough to make the over-all length 25 feet,

JET AIRCRAFT SIMPLIFIED

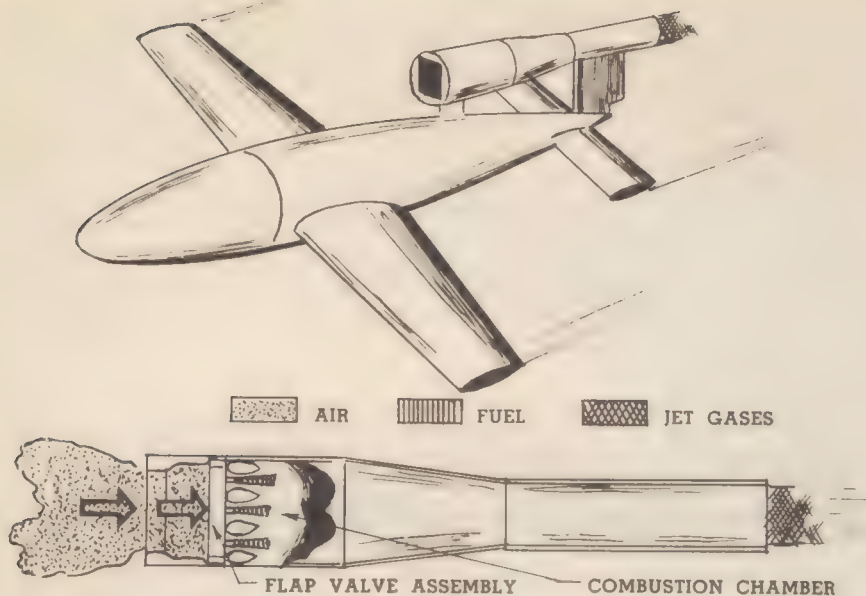


Fig. 5. The German V-1, or "buzz-bomb" of World War II.

4 inches. Except for the absence of a landing gear, the omission of ailerons, the V-1 looked very much like a small private airplane carrying an enormous stove-pipe over its tail. Gasoline was used as fuel.

The V-1 was an effective military weapon. In the summer of 1944, the Germans sent over England about 8,000 of these flying bombs. About 2,300 were reported to have hit targets, the remaining 5,700 being destroyed by British fighter airplanes, anti-aircraft fire and barrage balloons. Aside from the terrible destruction of lives and property by those that reached targets, the constant threat of the buzz-bombs shattered the nerves and reduced the efficiency of the English to an extent that cannot be calculated.

The pulsejet powerplant of the V-1 has been compared by American engineers to the Model T in the history of Ford automobiles. It was comparatively simple and cheap to make, even under wartime conditions in Germany, subjected as that country was to Allied bombardment. The military success of the V-1 is prophetic of what can be done with the pulsejet in guided missiles and some other forms of aircraft.

THE MARQUARDT PULSEJET HELICOPTER

The first publicly known pulsejet powered helicopter was designed and built by the Marquardt Aircraft Company, which at that time (1947-1948) was a subsidiary of The General Tire & Rubber Company.

This pulsejet helicopter, illustrated in Fig. 6, differs from conventional-type helicopters in that power is supplied by two pulsejet engines, one mounted on each tip of the rotary wing. Known as the Marquardt M-14 *Whirlajet*, it will carry twice the payload of a conventional helicopter for comparatively short distances because of the elimination of the usual heavy internal combustion

THE PULSEJET



Fig. 6. Marquardt pulsejet helicopter.

engine with its necessary transmission, clutch and free wheeling assemblies, together with the fuel, oil, ignition, and cooling systems.

The Marquardt pulsejet engine is an explosion type having reedlike valves in the air inlet as opposed to the ramjet or continuous burning engine of the athodyd type. Fuel and ignition are supplied through lines built integral with the rotor blade.

The elimination of the conventional equipment required for the powerplant of the usual helicopter permits a much lower comparative first cost and greatly reduces operational and maintenance costs. As progress is made in design and manufacturing, the pulsejet helicopter may be adapted to a wide range of both military and commercial uses. Commercially, it could be flown economically for short-haul operations of cargo and passengers, being particularly adaptable to airport-to-city shuttle service.

The *Whirlajet* was first flown at the Muroc Air Force Base and further ground, hovering, and flight tests were made at the Torrance, California, Municipal Airport. The Marquardt engineers reported that the craft was stable beyond their performance predictions in hovering and forward flight, largely because of the mass (weight) of the jet engines at the extreme tips of the rotor blades.

The *Whirlajet* has a gross weight of 1,000 pounds; the rotor diameter is 29 feet; there are two pulsejet engines; a dual control system; a conventional uniform and cyclic pitch control; a directional control with a controllable vertical surface hinged about a 45-inch inclined axis and actuated by rudder pedals. The fuselage is of welded steel tubing with wood and steel rotors of N.A.C.A. 8-H laminar-flow airfoil sections. Since this aircraft is experimental, performance data is not given. Future versions of pulsejet helicopters will probably make this pilot model look like a museum piece.

JET AIRCRAFT SIMPLIFIED



Fig. 7. American Helicopter Company's XH-26.

AMERICAN HELICOPTER COMPANY'S XH-26

The XH-26 is a one-man pulsejet powered helicopter that was developed by the American Helicopter Company of Manhattan Beach, California, and Mesa, Arizona. This project was started in June 1951 after American Helicopter won the military design competition for this type of aircraft.

The XH-26—shown in Fig. 7—has not yet been officially named, but has been unofficially dubbed the “Jet-Jeep” because its use in the air is quite similar to the jeep on the ground, and because its rugged simplicity reminds one of a jeep. Also, it can be carried in a jeep trailer, uses jeep fuel and jeep tool kit.

The ship stands six feet high and has a top speed of 80 miles per hour. Although the design empty weight is only 300 lbs., this little craft can carry a useful load of 600 lbs., or twice its own weight.

Since the jet motors that are mounted on the tips of the rotors are pure pulsejets as described in the first of this chapter, the motors require no warm up. And they will burn any low grade or high grade petroleum fuel such as gasoline, kerosene, or diesel fuel oil.

The tiny tail rotor, driven by belts, is not used as an anti-torque rotor, because no torque is generated in the fuselage with tip mounted engines. The purpose of the tail rotor is to improve directional control. Failure of the tail rotor would not hamper the pilot except possibly in high winds during precision maneuvers.

The tip mounted engines are free swiveling and automatically assume a horizontal position when started. Pitch of the blade can be changed without changing the position of the tip mounted engine.

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THE MARQUARDT PULSEJET-POWERED TARGET DRONE

Fig. 8 is a Marquardt pulsejet-powered target drone. The aircraft itself which is designated as the XKD5G is built by the Globe Aircraft Company, and the drone is powered by one of Marquardt's pulsejet engines. Although specific design data are not available and performance figures can not be quoted, it can be noted that this is another of our U. S. pilotless aircraft that has shown excellent performance and has proved to be a fast and maneuverable target for training purposes.



Fig. 8. Marquardt pulsejet-powered target drone.

SUMMARY OF PULSEJET CHARACTERISTICS

We can summarize the characteristics of the pulsejet thus:

Use: Guided missiles, target aircraft, helicopters, and emergency auxiliary power-plants.

Speed Range: This is a questionable characteristic. Disregarding helicopters, the speed should be at least as great as that of the athodyd, which may be assigned a theoretical maximum of 2,600 miles an hour. However, some engineers have given the pulsejet a practical maximum speed of 1,500 miles an hour. Obviously, the lower speed must be enough to start the ram effect. The true answers all lie in the future.

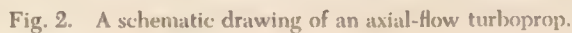
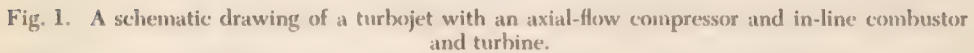
Advantages: Simple design, inexpensive to manufacture, high speed, light weight, ease of operation.

Disadvantages: Extremely high fuel consumption, vibration, noise.

THE TURBOPROP

The *turboprop*, also known as the *propjet*, consists of the basic turbojet engine and a reduction gear through which the turbine drives a propeller to obtain thrust, additional thrust being obtained from the jet exhaust.

Fig. 3 shows a turboprop essentially like Fig. 2 in principle except that in this drawing the mechanical features are developed further, revealing that there are several stages of compression obtained by a series of fans having rotating blades and that stationary blades (stator) are used to direct the flow of air. Also, there are two turbine wheels shown in order to convey the idea that a more complete expansion of the hot gases is obtained with a larger turbine (more stages).



THE TURBOPROP

In the turboprop, much of the energy in the hot gases of combustion is taken out in the form of mechanical energy to drive the propeller, as well as the compressor, leaving less energy in the jet than would be there if this were a turbojet engine of equivalent construction.

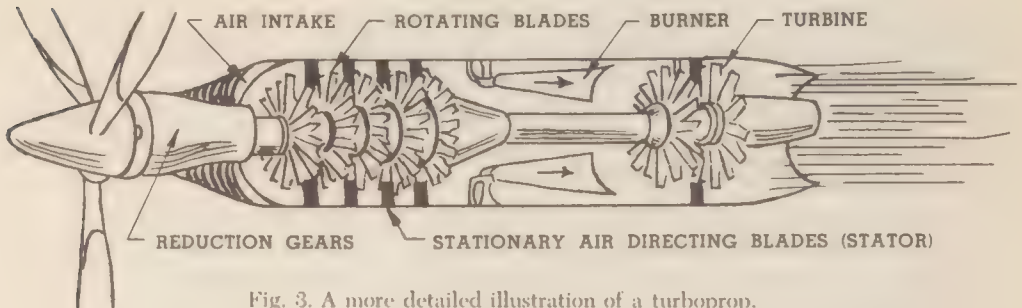


Fig. 3. A more detailed illustration of a turboprop.

GAINS AND LOSSES

The advantages of the turbine-and-propeller arrangement are that the engine can be designed to deliver the best possible shaft power while the propeller can be designed for the best possible handling of the large masses of air it whirls around and sends to the rear.

The propulsive efficiency of the turboprop is higher than that of the turbojet in the range of speeds below the speed of sound. However, with the turboprop there are losses caused by the drag of the propeller, gear losses, and other dissipations of energy. On the other hand, the efficiency of the propeller wake is very high, reaching more than 90 percent in certain designs when operating at speeds above 250 miles per hour.

An increase in the turbine inlet temperature of a turbojet engine may reduce its efficiency under certain conditions, whereas the same condition in a turboprop may improve its over-all performance. The reasons underlying this statement are involved, but the conclusion is valid enough to be listed as one of the factors favoring the selection of the propjet for some purposes.

The weight per pound of thrust is higher for the turboprop than it is for the turbojet at lower speeds because of the addition of the propeller, reduction gears, and turbine stages.

VERSATILITY OF APPLICATION

It should be remembered that the turboprop is a combination powerplant using the power generated by a gas turbine to rotate a conventional propeller, and that it uses substantially the same turbojet engine installed in the majority of modern jet-propelled airplanes except that the shaft is extended forward and drives a propeller through the necessary gearing. This is a simple and comparatively efficient mechanism. It can be adapted to all sizes and types of airplanes designed for any speed below 610 miles per hour and for operation at an altitude under about 35,000 feet. However, some authorities have made the statement that the turboprop is indicated for speeds below 500 miles per hour and under an altitude of about 30,000 feet. We shall now examine this topic in somewhat greater detail.

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RANGE, SPEED AND ECONOMY

Engineers have found in applying what they call the "inverse power law" that aircraft with top speeds between 335 miles per hour and 610 miles per hour reach their *maximum range* when turboprop engines are used. Applying the same law, they have found that aircraft designed for an extreme range between 2,500 miles and 9,500 miles have their highest top speeds when turboprops are used. From these two findings it may be concluded that the turboprop is the *most economical powerplant* for moderate to long ranges when operating at the cruising speeds we have considered appropriate for bombers and high speed transports in the past. In addition, it has been found that the take-off characteristics of the propjet are good.

A study made of airplanes carrying 40 passengers and operating from a runway 5,000 feet long, for a range of 1,000 miles, showed that the *fuel* burned in an airplane powered by turboprops represented about 27 percent of the direct costs of operation as contrasted with 30 percent for reciprocating engines and about 50 percent for turbojets.

At speeds between 400 miles per hour and 500 miles per hour, the range of an airplane driven by a turboprop was found to be almost twice that of a turbojet installed on the same airplane. This is in accordance with our previous comments on range.

When it comes to *flexibility*, the turboprop excels because it combines the characteristics of both the conventional airplane and the jet-powered craft.

The turboprop, in its present state of development, takes a place that the turbojet cannot fill so well, particularly where *range and take-off power* are important. Having proportionately high thrust at take-off and slower speeds, it offers power for particular jobs where no other type of powerplant can compete successfully.

At the so-called "moderate" speeds of from 400 to 500 miles per hour, and at medium to long operating ranges, the turboprop delivers high power aided by the highly developed and well known efficiencies of the conventional propeller. Unlike the reciprocating engine, it can deliver a high percentage of its total power with comparatively low fuel consumption, a characteristic which adapts it to efficient long-range flight operations.

LIMITED IN SPEED BY CURRENT PROPELLER EFFICIENCY

The efficiency of the propeller in its present state of development is the principal reason why the turboprop must fly below the speed of sound. If and when the propeller is developed further, it may be possible to fly at or above the speed of sound with a propjet powerplant.

POSSIBLE AVENUES OF PROPJET IMPROVEMENT

Disregarding the limitation placed upon the sonic flight of the turboprop by its propeller, there are several possible avenues of turboprop improvement, all of them suggested by past attempts to improve the efficiency of the turboprop's basic unit, the turbojet engine. Many of these have been tried already, some of them have been successful and others have been partially successful but brought new problems in their trains.

THE TURBOPROP

For example, centrifugal-flow air compressors which compress the air radially, out from the center of the impeller, have been used. Also, axial-flow compressors which compress the air in a series of fan-like stages, in a straight line, have been used. Furthermore, both the centrifugal-flow compressors and the axial-flow compressors have been used in combination with each other.

It is well known to engineers that the compression of air in the first stage of compression heats it and makes it proportionately more difficult to compress it in the second stage, hence they have used *intercooling*, in which the air is cooled after the first and following stages of compression so that it can be compressed easier in the second and later stages.

Regeneration, which is the use of the exhaust to preheat the compressed air before it reaches the burners, has been tried.

Reheating, which is the injection of fuel at various stages of the turbine after the first stage is another attempt to improve efficiency.

Afterburning, which is the injection of fuel into the exhaust stream after the turbine to increase the jet effect, has been mentioned before in connection with turbojets, but it should be considered as applicable to propjets as well.

TURBOPROP CONTROL

Since the gas turbine is a constant-speed powerplant and has its lowest specific fuel consumption at maximum power, its performance is basically limited by the maximum permissible r.p.m. of its rotating elements and the maximum permissible temperature for the units and parts exposed to the hot gases of combustion. Consequently, the control system for the turboprop must be more precise than that developed for the conventional reciprocating engine.

Aeronautical engineers specializing in powerplant design approach this problem from two different viewpoints. One group insists that the temperature (and hence the power) of the turboprop should be controlled by adjusting the flow of fuel and that the r.p.m. should be controlled by adjusting the blade angle of the propeller. This follows the thinking of those who developed the control system of the old piston-type engine.

The other group approaches the problem from a directly opposite direction. These engineers say that the control of temperature (and hence the power) of the turboprop should be accomplished by adjusting the angle of the propeller blades and that the control of the r.p.m. should be accomplished by adjusting the fuel flow. This statement is so startling that it should be read carefully twice, but before it is rejected it should be examined in the light of all that we know about the turboprop powerplant. There is merit in both methods of engine control.

ALLISON TURBOPROP ENGINES

Allison Models

Allison models which we should consider are the Allison T38 and the Allison T40, both made by the Allison Division, General Motors Corporation, Indianapolis 6, Indiana.

JET AIRCRAFT SIMPLIFIED

Allison T38

The Allison T38 (also known as Model 501-B), which is not considered a current model, was intended for the U. S. Navy. It has a 17-stage axial compressor, 8 combustion chambers, 1 propeller shaft, and a 4-stage turbine. The length of the engine without the propeller is 84 inches, the diameter is 20 inches, the frontal area is 4.3 square feet, and the weight is 1,225 pounds.

Allison T40

The Allison T40, also known as the Allison T40-A-6, was developed for the U. S. Navy and has a static rating of 5,500 horsepower. The engine has twin power sections connected by extension shafts to a reduction gear driving contra-rotating propellers. Each power section drives both propellers, and for cruising, single power sections can be declutched for maximum fuel economy.

When a single power section is used with a single rotation reduction gear and propeller for a complete engine with one-half the horsepower of the T40, we then have the Allison T38 turboprop previously described.

Among the U. S. aircraft powered with Allison turboprop engines are: (1) The Convair XP5Y produced as the R3Y Tradewind, Fig. 4, a seventy-ton flying boat using four T40 Allison turboprop engines; (2) The Douglas A2D Skyshark, a carrier-based attack bomber, powered by one T40 Allison turboprop engine illustrated in Figs. 10 and 11; (3) The North American XA2J Savage, carrier-based attack bomber, powered with two Allison T40 turboprop engines; and (4) The Allison Turbo-Liner, actually a standard Convair "240" passenger transport which was purchased by Allison and modified for installation of two T38 turboprop engines. This airplane has been used to proof-test turboprop engines in transport-type aircraft, and was one of the first commercial-type turbine transports in the United States.



Fig. 4. The Consolidated-Vultee XP5Y-1 flying boat.

THE TURBOPROP

BOEING TURBOPROP ENGINE

The Boeing T50, also known as the Boeing Model 502 turboprop engine, illustrated in Fig. 5, weighs only 140 pounds in its original form, and yet it can deliver more than 200 horsepower. This is compared with a weight of about 500 pounds for the usual 90-horsepower automobile engine.

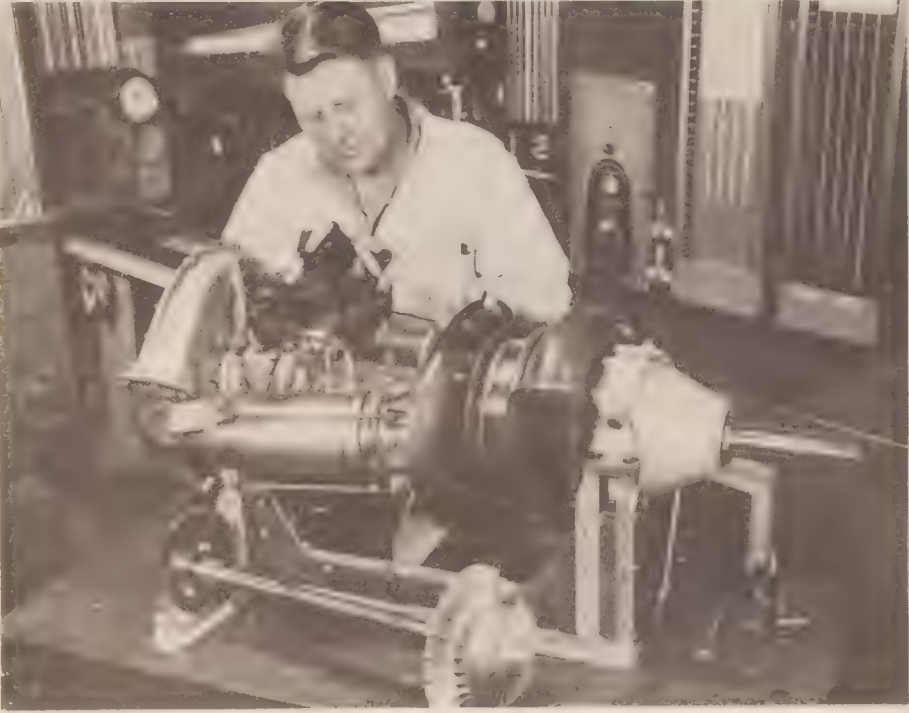


Fig. 5. The Boeing Model 502 turboprop.

This turboprop has a 1-stage centrifugal compressor, two combustion chambers, one propeller shaft, and a 2-stage turbine. It is of the two-burner type (as the phrase 2-stage turbine indicates), and develops its power through the use of a quick-burning air and fuel mixture, which turns a small turbine wheel, only 7½ inches in diameter in the original form. The waste exhaust produces a total of 50 pounds thrust as an added means of propulsion. It can power a small airplane, a boat, or machinery operated by stationary power.

This powerplant was originally made by Boeing research engineers solely to increase their knowledge of jet propulsion. It is not yet in commercial production and it is too early to prophesy accurately what can be done with it. However, it does offer possibilities as a powerplant for light aircraft and might hasten the advancement of jet propulsion in that field.

GENERAL ELECTRIC TURBOPROP

TG-100 B Turbojet Engine

Fig. 6 is a schematic drawing of a turboprop developed by the General Electric Co. during World War II, but never put into production. Air enters

JET AIRCRAFT SIMPLIFIED

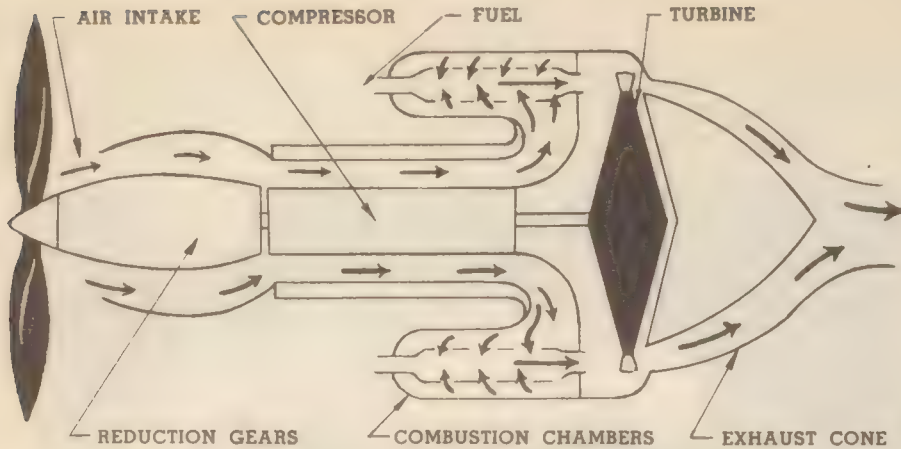


Fig. 6. A schematic drawing of the turboprop developed by General Electric Co.

through the air inlet at the front of the engine, and passes into the compressor. Here its pressure is multiplied by the hundreds of blades packing it into smaller and smaller space. Forced into the combustion chambers, it is mixed with atomized fuel. Constant burning increases the energy of the compressed air and forces it to expand through the turbine and out through the tail cone. The turbine, operating like a windmill, supplies the power to spin the compressor and drive the propeller. The expanding gases, pushing their way out the rear at high velocity, provide some jet thrust in addition to the propeller power.

Fig. 7 is a cutaway drawing of the same turboprop, which was known to General Electric as the TC-100B, and known to the U. S. Army Air Force as the A.A.F. T-31-GE-3. Important units and parts are labelled in the drawing.

Northrop Turbodyne Bought by General Electric

In 1950, the General Electric Co. purchased the right to use the corporate name, certain patents and technical data of the Turbodyne Corporation, a research subsidiary of Northrop Aircraft, Inc., of Hawthorne, California, which had developed a turboprop then believed to be the most powerful of its kind in the world. However, the jet engines in production by General Electric have been turbojets rather than turboprops. Nevertheless, the research efforts of General Electric in the turboprop field are well worth recording.

PRATT & WHITNEY TURBOPROP

Fig. 8 is a photograph of the turboprop manufactured by Pratt & Whitney Aircraft Division of United Aircraft Corporation, East Hartford 8, Connecticut. Fig. 9 shows this engine being tested by factor yengineers. It is known generally as the Pratt & Whitney T-34, but more technically as the T34-P-2 (Turbo-Wasp PT-2). The T34-P-1 is similar. It has a 13-stage axial compressor, one annular combustion chamber, one propeller shaft, and a 3-stage turbine. The diameter is 30 inches, the length is 155 inches, the frontal area is 4.9 square feet, and the weight without the propeller is 2,550 pounds. The static rating for take-off is 5,700 horsepower.

THE TURBOPROP

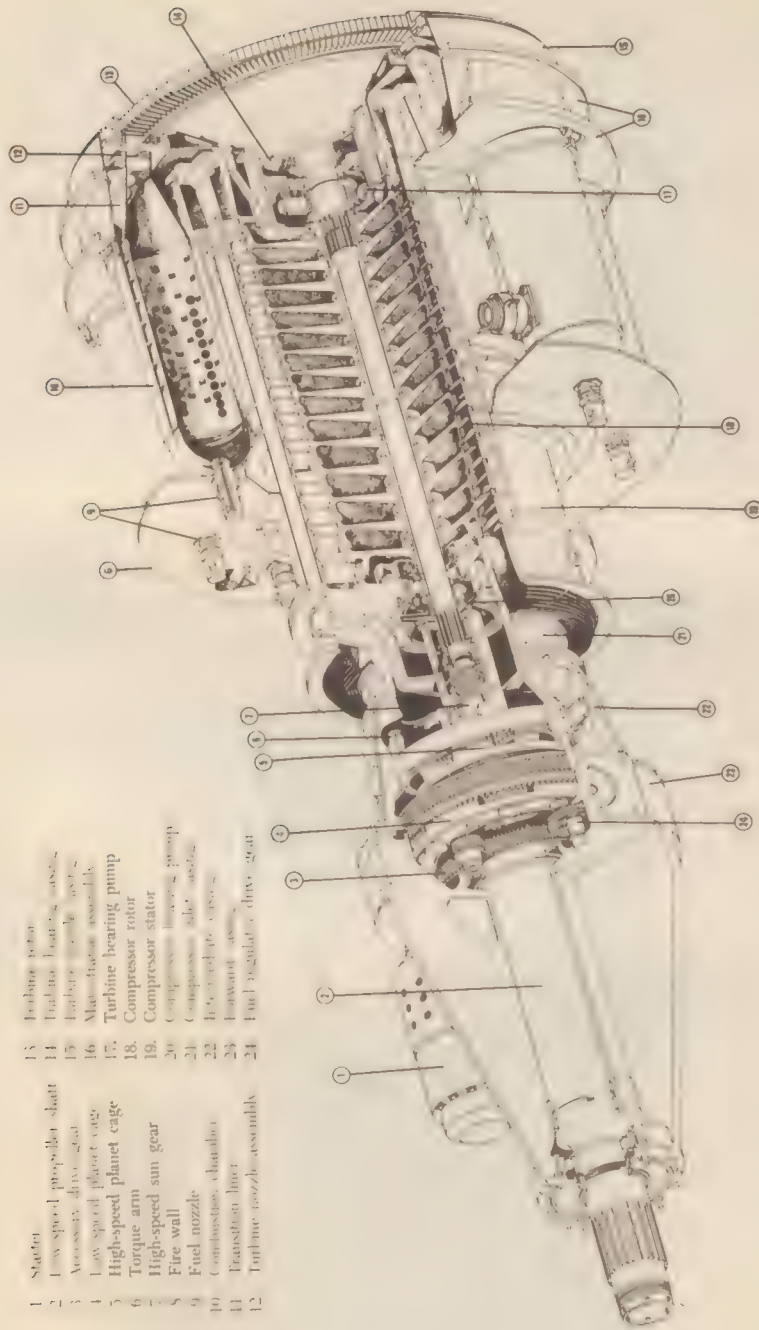


Fig. 7. The General Electric TC-100B (A.A.F. T-31-GE-3) propjet.

JET AIRCRAFT SIMPLIFIED

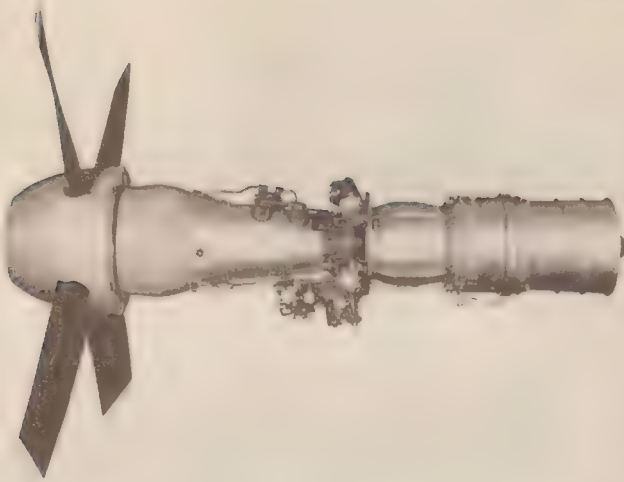


Fig. 8. Pratt & Whitney turboprop.

This turboprop has been installed in the Lockheed R-7V-2, a Super Constellation built for the Navy, and in the Douglas YC-124-B, built for the U. S. Air Force, a larger version of the Douglas Globemaster heavy transport.



Fig. 9. Pratt & Whitney turboprop receiving factory tests.

THE TURBOPROP

APPLICATIONS OF TURBOPROP POWER TO AIRCRAFT

Evolution of Power Plant Studies for Douglas A2D Airplane

Fig. 10 is a panel of five drawings prepared by Douglas Aircraft Co., Inc., to show the evolution of power plant studies that led to the A2D airplane power plant arrangement. From the top we have (1) A Wright R-3350 piston engine is installed in the airplane; (2) The General Electric TG-100 turboprop is drawn to show how it would look, but the engine was not delivered, hence it was never flown in the airplane; (3) A composite jet and turbine engine arrangement was developed by Douglas but not built. This arrangement used two Westinghouse 24C jet engines arranged so that their exhaust would drive a turbine wheel, which in turn drove two opposite rotating propellers; (4) A jet power plant consisting of two Westinghouse 24C engines appeared promising, but did not meet the take-off and endurance requirements in this particular application; and (5) The final power plant used in the A2D consists of a double Allison T40 power plant driving a coaxial propeller through a reduction gear.

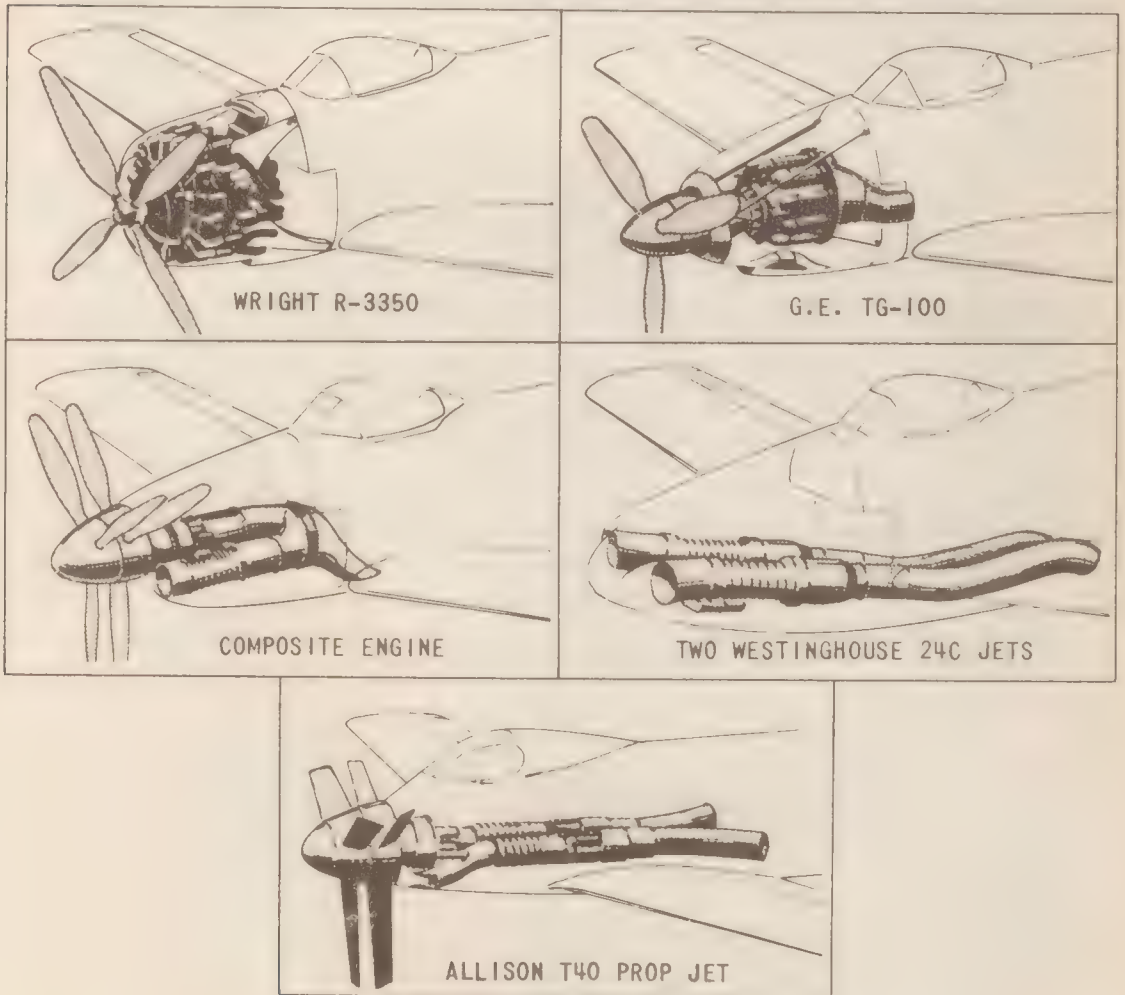


Fig. 10. Evolution of power plant studies for Douglas A2D airplane.

JET AIRCRAFT SIMPLIFIED



Fig. 11. Douglas A2D in flight.

Fig. 11 shows the A2D in flight. This airplane is able to take off in less than $\frac{2}{3}$ the distance of comparable jet fighters and less than $\frac{1}{3}$ the distance of comparable jet bombers. Likewise, the high static thrust of the T40 engine permits the A2D airplane to operate from even the smallest (CV-55) aircraft carriers with ample deck length margin.

LOCKHEED C-130 ASSAULT FREIGHTER

This is America's first turbo-prop transport — designed to fly higher, faster and more economically than any existing military transport. It will be used for front-line aerial assault and ground-to-ground support. Designated C-130, the long-range plane is equipped to fly troops, including paratroops, and military cargo to front lines. As a hospital plane it will accommodate litter patients and attendants. This first photograph of a scale model illustrates how the rear cargo door becomes a loading ramp for straight-in loading at truck-bed height, or can be lowered to permit heavy vehicles to drive in and fly away. The Lockheed craft, America's first transport originally designed for turbo-prop engines, requires only short takeoff and landing runs. The powerplants are new modernized versions of the Allison T38 turboprop jet engine, which turn Curtiss-Wright three-bladed turbopropellers. It has unusual landing gear, with main units arranged in tandem to facilitate operation from small fields or rough forward airstrips. The entire fuselage is pressurized. Wingspan is 132 feet, length 95 feet, height 38 feet. Prototyps are under construction at Lockheed's Burbank, Calif., factories. A quantity production order has been assigned to Lockheed's plant in Marietta, Ga.

LOCKHEED SUPER CONSTELLATIONS WITH TURBOPROPS

The original Constellation was designed in 1943 as a 72,000 pound airplane and had a cruising speed of 305 miles per hour. Then in 1951-1952 that airplane was modernized with greater length and greater power to bring its gross weight up to 133,000 pounds with a maximum cruising speed of 340 m.p.h. Now the Lockheed engineering department has already designed a still newer version of this famous airplane which is expected to fly at 425 m.p.h. with turboprop engines. If the turboprop engine developments progress satisfactorily, this newest "Super Constellation" is planned for a gross takeoff weight of 150,000 pounds, which is more than double the lift of the first models.

THE TURBOPROP



Fig. 12. Lockheed C-130 Assault Freighter

SUMMARY OF TURBOPROP CHARACTERISTICS

Use: Any airplane where flexibility is desired, or where cruising for moderate to long ranges will permit this type in order to save fuel. It is particularly suited for new cargo aircraft in the 300 m.p.h. and 400 m.p.h. speed range; for re-engining existing transport aircraft which have relatively low basic design speeds; and for the short-range feeder-type operation under 400 miles in distance.

Maximum speed range: With current equipment, about 610 miles per hour, but the development of new turboelectric propellers may pave the way for turboprop speeds up to 1,000 miles per hour.

Advantages: (1) It has good take-off characteristics; (2) Propellers can be used for reversing on landing; and (3) It has relatively good economy of fuel consumption, particularly in the case of the more modern engines.

Disadvantages: The typical turboprop engine is more complex than the usual turbojet type. It has the same problems of jet operation in that section of the engine where power is developed. It has as many flame tubes, turbine and compressor blades, and other parts, and a more complicated fuel system. In addition, the turboprop engine has a gear box, high-speed shafting, and a propeller which weighs as much as the turboprop engine itself in some models.

The propeller adds to the starting problem because it has a high inertia and starting drag. After the turboprop engine starts, it idles at 80% to 90% of the cruising r.p.m., creating additional noise.

CHAPTER VI

THE TURBOJET

DEFINITION

The *turbojet* is a thermal-air-jet engine in which the incoming air is compressed by a compressor, heated by burning fuel at compressor pressure, released through a turbine that drives the compressor, and then ejected at high velocity through the exhaust nozzle at the rear. This engine delivers all of its thrust by the rapid exhaust of hot gases from the tail pipe (jet nozzle). The turbine is used only for driving the compressor. At the present time, this is the most widely used of all the jet-type powerplants.

In our study of the ram-jet family, we learned that the athodyd and the pulsejet depend upon air being "rammed" into the front of the duct (tube) by the fast forward speed of the aircraft. In other words, both the athodyd and the pulsejet lack any mechanical means of compressing the intake air, but the turbojet depends upon a mechanical compressor.

The turbojet is a combination of the open-cycle gas turbine with the athodyd. An air compressor is mounted forward, ahead of the combustion chamber, and a one or two-stage turbine is at the rear of the combustion chamber on the same shaft. The turbine absorbs only enough of the heat energy to operate the compressor and accessories; the remaining energy goes into the high-velocity exhaust jet and is violently ejected to the rear to develop thrust. By increasing the combustion pressure, the compressor (operated by the gas turbine) adds greatly to the efficiency of the athodyd.

FLOW DIAGRAM

Fig. 1 is a schematic flow diagram of the Allison J-35 Turbojet Engine. Notice that the engine is essentially a tube, open at both ends. The outside air enters through the *air inlet* and is squeezed together by the *compressor*. The compressed air is then directed to the *combustion chamber*, where fuel nozzles spray a continuous stream of fuel (usually kerosene or gasoline at present) into the air. This fuel combines with part of the air to form a burnable mixture, just as it does in any internal combustion engine.

An *ignitor plug* is used to start the fuel-air mixture burning and after this first ignition it burns continuously as long as the temperature of the combustion chamber is high enough to ignite each new particle of the mixture as it is formed.

The burned fuel-air mixture expands enormously and the heat also expands all of the extra air which was not mixed with the fuel. The pressure increases and the mixture of air and the gases of combustion tries to escape as fast as possible. In its effort to escape to the rear, it runs up against an obstacle. This is the *turbine*, mounted on a shaft which runs the compressor.

The hot gases strike the blades of the turbine and make it go around at a high speed, just as steam turns a turbine in an electric generating plant. Since

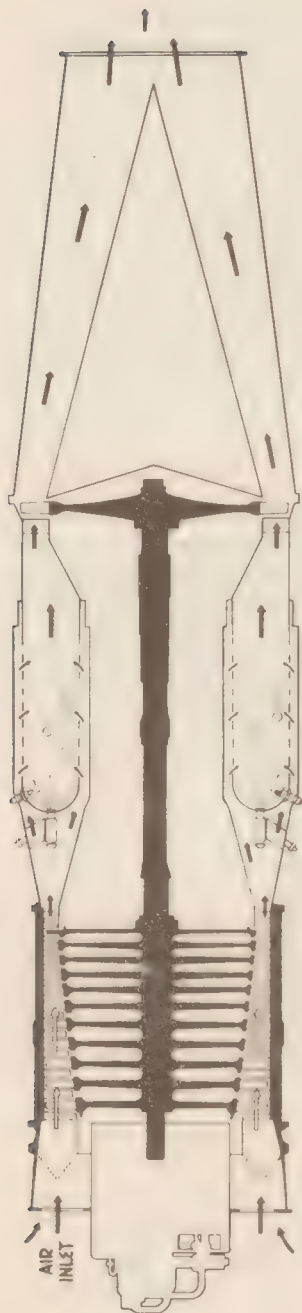


Fig. 1. A schematic flow diagram of the Allison J35 turbojet An axial-flow turbojet engine.

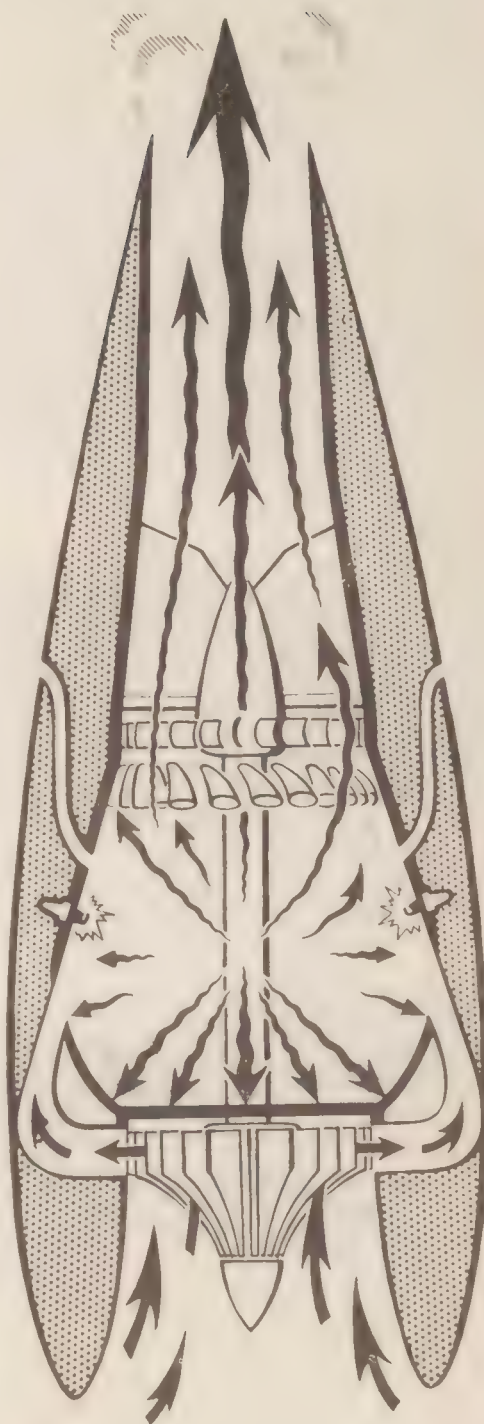


Fig. 2. A schematic flow diagram of the Allison J33 turbojet A centrifugal-flow turbojet engine.

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the turbine and the compressor are mounted on the same shaft, the turning of the turbine drives the compressor. Remember, the turbine has nothing to do with the actual driving of the airplane. Its sole function is to drive the compressor.

Some of the energy in the hot gases is consumed in driving the turbine, but by no means all of it. The gases keep pushing toward the rear of the tube after they leave the turbine, as shown in Fig. 2, which is a schematic drawing of a centrifugal type engine used in the Lockheed F-80 *Shooting Star*.

The tube becomes narrow at one point to form a *nozzle*. This increases the speed of flow and the gases, still very hot, shoot out into the outside atmosphere at the rear at a very high speed. This is the jet which drives the airplane through the air.

There must be an electric motor or some other means of rotating the compressor in order to start the operation of the engine. After operation has begun, the turbine drives the compressor. It is essentially the same system as the turbosupercharger used on some large aircraft reciprocating engines, except that in the turbosupercharger the waste exhaust gas from a piston-type engine is being used and in the turbojet we take part of the energy from the gases which are used to drive the airplane.

In the turbojet, a vastly greater amount of power is being used to compress air than in a turbosupercharger; in fact, a surprisingly large percentage of the total power developed in the combustion chamber of the turbojet is used to operate the compressor. The compressor of the turbojet handles more air and it may develop a higher pressure than any supercharger. The pressure developed by the compressor must be greater than the pressure of the jet at the rear end of the airplane because otherwise the jet would blow out at the front as well as at the back.

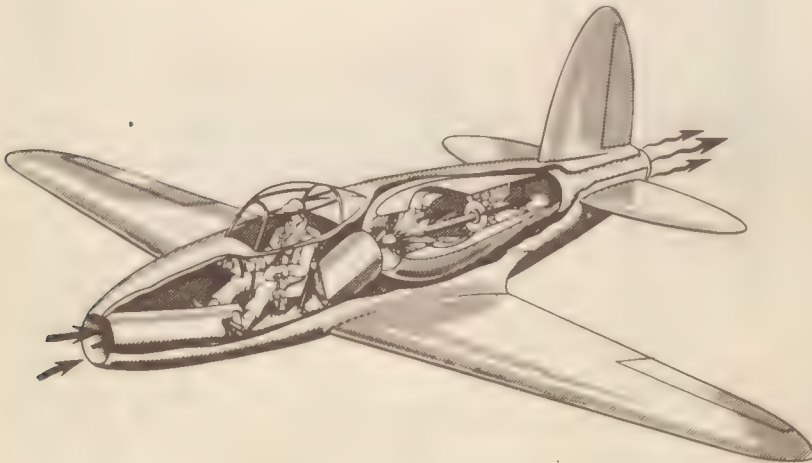


Fig. 3. A cutaway drawing that illustrates the method by which a turbojet engine drives an airplane.

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HOW THE TURBOJET DRIVES THE AIRPLANE

Fig. 3 is a cut-away drawing that illustrates the method by which a turbojet drives an airplane. As explained before, air is drawn into the engine at high compression by means of a high-speed fan-like compressor. From the compressor it passes into a combustion chamber where it is mixed with fuel injected at high pressure. A continuous explosion occurs in this combustion chamber, similar to the explosion in the athodyd engine of the ramjet family. This explosion heats the gases of combustion to a very high temperature and causes them to expand violently.

We now have a condition similar to that created in the sphere with an opening in one side that we discussed in an earlier chapter. The exploded mixture under great pressure can move in only one direction and that is toward the back of the airplane, where there is a comparatively low pressure. The pressure at the sides of the combustion chamber are equal and there is a very high pressure at the front of the chamber. This condition of unbalanced forces is responsible for the thrust.

A FORMULA FOR JET PROPULSION

In high school physics we were taught that Force equals Mass multiplied by Acceleration. This is written: $F = MA$. Instead of using the word acceleration, we can substitute the phrase "increased velocity" and we have: Force equals Mass multiplied by Increased Velocity. Applied to jet propulsion, F , the force driving the airplane equals M , the mass of the expanding gas, multiplied by A , the increased velocity given to the gas as it expands and passes to the outside atmosphere at the rear.

AXIAL-FLOW AND CENTRIFUGAL-FLOW TURBOJET

Fig. 4 shows an axial-flow turbojet engine with its air intake, oil cooler, compressor section, combustion chamber, turbine, and adjustable tail section. The arrow and lines at the rear indicate the exhaust thrust.

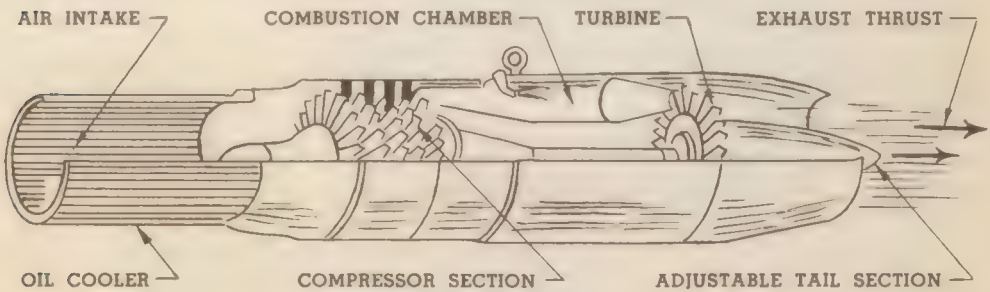


Fig. 4. An axial-flow turbojet engine.

Fig. 5 shows a centrifugal-flow turbojet engine with its diffuser, impeller, several combustion chambers arranged around the axis like a ring, the turbine, and the exhaust cone. The arrow and lines at the rear indicate the exhaust thrust. The diffuser and impeller, taken together, constitute the air compressor. The impeller is, in many models, a double-sided multiple-vaned wheel which is enclosed in a casing with the diffuser, which breaks up and spreads out the incoming stream of air. The *exhaust cone* is sometimes called a *tail cone*.

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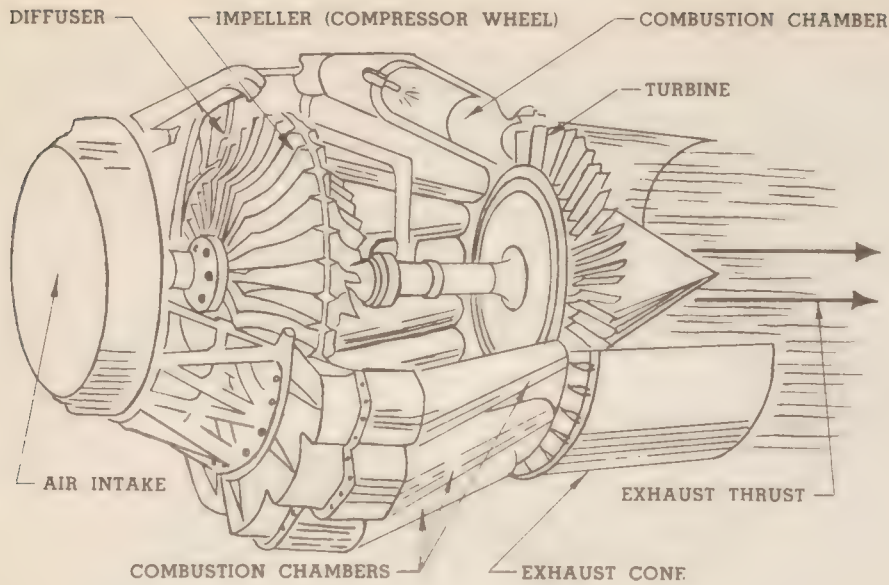


Fig. 5. A centrifugal-flow turbojet engine.

These two classes of turbojets take their names from the compressors they use. The principle of operation is fundamentally the same for both types. The air is taken into the unit by the compressor (or impeller and diffuser), and its pressure is raised several times. This compressed air is then fed into a single combustion chamber or it may be fed into a ring of several combustion chambers. The subsequent flow is essentially the same for both types and follows the course previously explained.

The operation of a turbine may require some brief discussion. The dictionary definition is: "A rotary motor actuated by the reaction, the impulse, or both, of a current of water or steam, usually on a series of curved vanes on a central spindle." That definition should be brought up to date to include gas.

In a gas turbine, the compressor and the turbine are on the same shaft and spin together. The rush of hot gases strike the cupped blades of the turbine, causing it to drive the shaft and thus rotate the compressor, which acts something like a ventilating fan of a building to suck in the outside air.

Both the axial-flow compressor and the centrifugal-flow compressor possess certain advantages as well as disadvantages. The axial-flow type is made with a smaller diameter, hence the frontal area of the turbojet equipped with this type of turbine is smaller and there is less drag as the airplane travels through the air. The engine is slightly longer than that of the other type. There is a straight-line flow of air and gases from the front to the rear, providing a better ramming action than the centrifugal type. The chief disadvantage is that this type weighs more than the centrifugal-flow turbine.

Conversely, the centrifugal-type compressor possesses a larger frontal area, causes more drag, and provides a poorer ramming action, but weighs less, and the engine is shorter.

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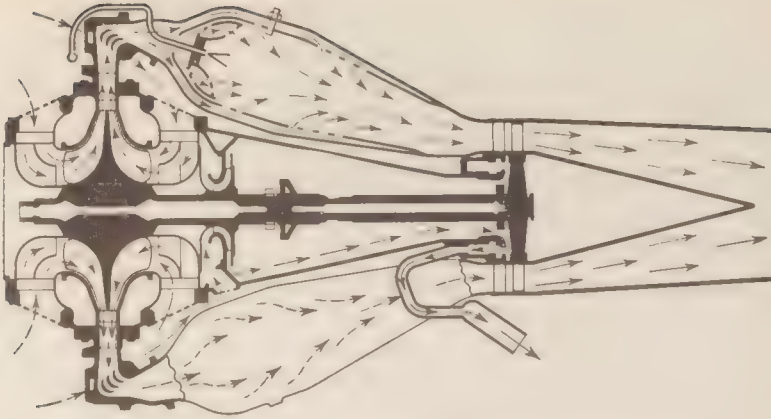


Fig. 6. The through-flow type of centrifugal-flow turbojet.

THROUGH-FLOW AND REVERSE-FLOW CENTRIFUGAL TURBOJETS

Centrifugal-flow turbojets are subdivided into two lesser types: Through-flow and Reverse-flow. In the through-flow type, illustrated in Fig. 6, the air goes through the impeller and is directed to the rear but slightly inward to travel directly through the turbine and out through the exhaust. The engine is slightly longer than that using the reverse flow, but the operation is more powerful and efficient.

In the reverse-flow type, illustrated in Fig. 7, the air is taken in through the impeller, compressed, and then turned 90 degrees and directed toward the rear. There, to save length and the added weight of additional bearings and shafting, the air is turned 180 degrees and sent into the combustion chamber. After the air is mixed with fuel and burned, the hot gases and air are turned 180 degrees once more in order to obtain thrust in the correct direction and pass through the turbine and out the exhaust jet. This round-about route saves over-all length

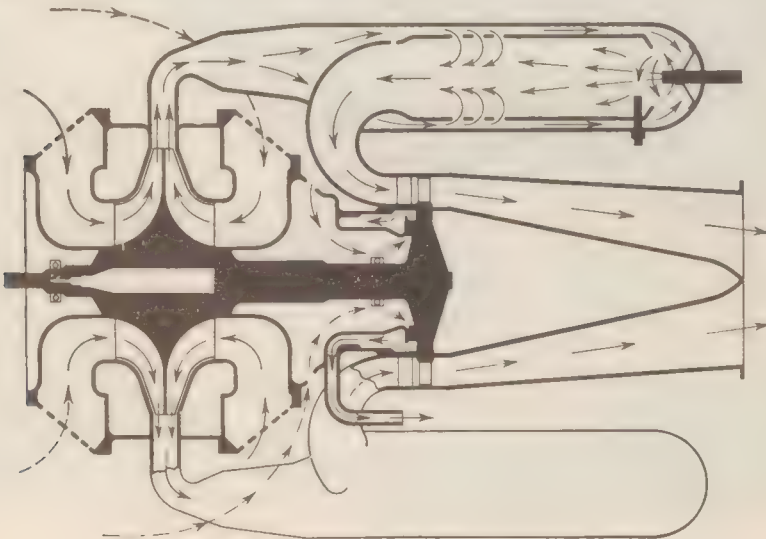


Fig. 7. The reverse-flow type of centrifugal-flow turbojet.

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and materials, but it causes a loss of both power and efficiency. The reverse-flow was used in the early centrifugal-type turbojets made by Whittle in England and by the General Electric Company in the United States but it is not employed in modern engines.

FUEL

All of the common fuels can be burned in the turbojet, including kerosene, gasoline, diesel oils, and tar oils. However, the selection of fuel for the turbojet requires consideration of engine design, operating conditions and the type of flying to be done. Good combustion efficiency, easy starting at low temperatures, low freezing point and availability in large quantities are desirable qualities.

For commercial flying there is some demand for a low volatility fuel such as the commercial grade of kerosene in order to reduce the fire hazard, obtain a greater heating value per gallon, less vapor locking, and less evaporation tendencies, but it is not available in large quantities and it causes more difficult starting at extremely low temperatures. The two disadvantages outweigh the advantages for military flying and lead to the use of gasoline in most cases.

LUBRICATING OILS

✓ The extremely low starting temperature and the moderately low operating temperature (comparatively speaking) of the turbojet lead to the selection of a low viscosity lubricating oil. This type of oil is also chosen for the gears and bearings if the loads are light.



Fig. 8. A photograph of a turbojet showing the hot gases roaring from the engine.

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TAILPIPE BURNING OR AFTER BURNING

A great increase of power can be given an aircraft jet engine by the use of a newly developed thrust-augmentation technique known as "after burning" or "tailpipe burning" and illustrated in Fig. 8, which is a photograph of a test house at the General Electric Company's aircraft gas turbine factory at Lynn, Massachusetts. This photograph was made with the aid of infra-red film which shows the hot gases roaring from a J-35 Turbojet. The exhaust gases are not visible to the naked eye.

The use of the afterburner on seven entirely different turbojet engines operated in the United States in 1953 increased the thrust output as much as 40 percent above the static thrust at take-off without the afterburner for some engines and averaged about 33 percent for all seven engines. These were take-off conditions. Under high-speed and high-altitude flight conditions, the increase can be 100 percent or more.

A COMPARISON OF TURBOJET AND RECIPROCATING POWER UNITS

Fig. 9 consists of drawings showing a complete cycle of four strokes of a reciprocating engine below a drawing of a gas turbine engine with a multistage axial compressor and a single-stage turbine. The intake cycle of the piston-type engine is directly below the inlet section of the turbojet engine. Compression, combustion and exhaust correspond for the two types of powerplants illustrated. It must be remembered that the piston-type engine has intermittent explosions but the turbojet engine produces power continuously.

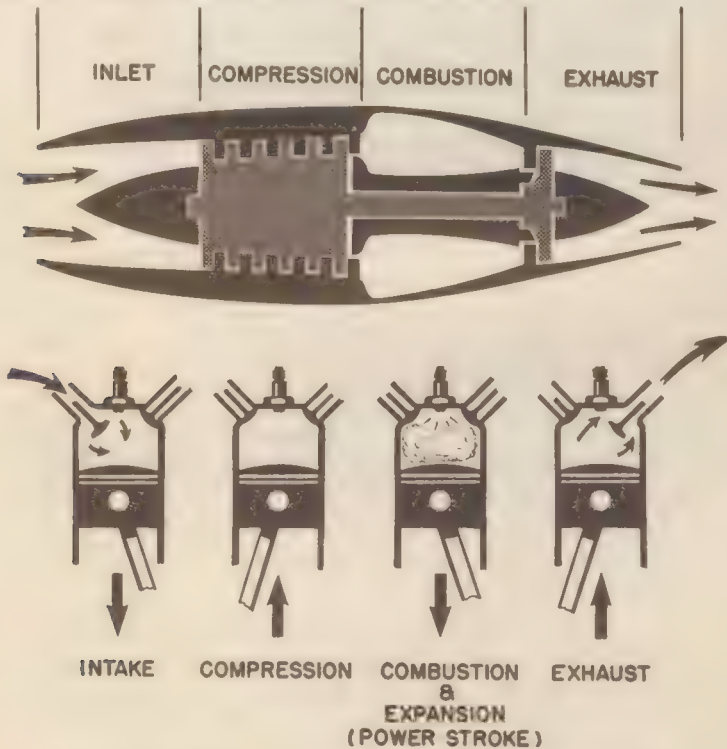


Fig. 9. A comparison of turbojet and reciprocating power units.

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AVAILABLE POWER AS A MEANS OF COMPARING TURBOJET WITH TURBOPROPS

In order to permit a comparison of the efficiencies of turbojet and turboprop engines, the ratio of the power available for propulsion to the total power available can be taken as a reliable index. The maximum efficiency of a turbojet with no friction loss in the tailpipe or nozzle is theoretically about 50 percent, but in practice it is only about 47.5 percent.

In the turboprop engine the total power depends on the ration of the power taken out to drive the propeller to the total power available. When this ratio is selected to provide the greatest propulsive efficiency, the propjet may be much more efficient than the turbojet up to speeds much higher than 500 miles per hour, the upper limit of speed which has been given frequently as its limit for maximum efficiency.

TURBOJET, TURBOPROPS AND RECIPROCATING ENGINES COMPARED ACCORDING TO THE INVERSE-POWER LAW

Engineers have a formula based upon what they call the "inverse power law" which they can use for comparing the performance of the various types of powerplants. An explanation of the formula and the law upon which it is based is beyond the scope of this text, but we can present the conclusions formed by an application of the formula.

Aircraft with top speeds above 610 miles per hour reach their maximum *range* when turbojet engines are used. Aircraft with top speeds below 335 miles per hour reach their *maximum range* when reciprocating engines are used. Aircraft with top speeds between 335 miles per hour and 610 miles per hour reach their *maximum range* when turboprop engines are used.

Aircraft designed for extreme ranges greater than 9,500 miles have their *highest top speeds* when reciprocating engines are used. Aircraft designed for extreme ranges less than 2,500 miles have their *highest top speeds* when turbojet engines are used. Aircraft designed for an extreme range between 2,500 miles and 9,500 miles have their *highest top speeds* when propjet engines are used.

In general, the turboprop is the most economical powerplant for moderate to long ranges when operating at the cruising speeds we have in the past considered appropriate for bombers and high-speed transports. Also, the take-off characteristics of the propjet are good.

OPERATING CHARACTERISTICS

The *thermal efficiency* of an engine may be regarded as the percentage of the total fuel energy which is made available by the engine for propulsion. The turbojet compressor provides a compression ratio of three to four, even at a standstill, and a higher compression ratio in flight. This is higher than that of the athodyd at a flight speed of 1,200 miles per hour, and higher than that of the pulsejet at the speed of sound.

The *propulsive efficiency* is the percentage of total energy made available by the engine for propulsion which is effective in driving the airplane. For more current uses of jet-type engines, the turbojet leads in propulsive efficiency.

Over-all efficiency is the percentage of the total fuel energy which is actually effective in driving the airplane. It can be found by multiplying the thermal

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efficiency by the propulsive efficiency, hence, for most current purposes, the turbojet has the greatest over-all efficiency of any of the jet engines.

Compared with the reciprocating, piston-type engine, the turbojet is structurally simpler, more streamline in contour, has one-fourth the displacement and less than one-half the weight of the equivalent rated reciprocating engine, fewer instruments, and simpler operation. In the cold, thin air of higher altitudes, the drag of the turbojet is reduced and its engine efficiency is increased, thereby adding to the range. At low speeds and altitudes, the turbojet at present suffers in comparison with the conventional-type engine because of excessive fuel consumption and reduced thrust, thus limiting its current use to airplanes in which speed is more important than range or payload. However, it is predicted that future models may rival the piston-type engine in both fuel economy and range.

ENGINES FOR COMMERCIAL AIR TRANSPORTATION

Various studies have been made of the comparative value of different types of powerplants for commercial air transportation. In making comparisons, it was found that cost, availability, installation features, inspection and repair characteristics, operating life, cruising speed, altitude, pay load, range, reliability, and efficiency of engine performance were all interrelated. Although we shall not examine all of these factors affecting the choice of an engine for an air transport, we shall consider enough to observe the trend.

At the beginning, we can safely eliminate rockets, athodyds and pulsejets for reasons apparent to anyone who has read the earlier chapters of this text. This leaves the conventional piston-type or reciprocating engine, the turbojet, and the turbine-propeller combination that we call a turboprop for convenience.

Fuel loads: Comparing fuel loads required for the reciprocating engine, the propjet and the turbojet for a range of 1,000 miles, with an airplane carrying 40 passengers and operating from a runway 5,000 feet long, the following fuel loads (in pounds) were required when operating at the cruising speeds shown in the table:

Type of Engine	Cruising Speed	Fuel Load in lbs.
Reciprocating	300 m.p.h.	5,650
Propjet (or turboprop)	440 m.p.h.	10,300
Turbojet	500 m.p.h.	24,000

Fuel Costs: Considering all of the direct costs of operating airplanes, leaving out overhead, the fuel burned in airplanes driven by propjets represented about 27 percent of the costs, that consumed in airplanes powered by reciprocating engines was about 30 percent, and that used in turbojets was about 50 percent.

Operating Costs per Ton-Mile: The operating costs per ton-mile increase noticeably for a turbojet with an increase of range, but for ranges greater than 1,000 miles the cost of operating a propjet per ton-mile does not increase appreciably.

Range: Assume that we have two engines of equal efficiency in themselves and install them in identical airplanes. One engine is a turbojet and the other is a propjet. At speeds between 400 and 500 miles per hour it has been found that the range of the propjet may be almost twice that of the turbojet. This relative efficiency is explained by a law that says that for any given expenditure of energy

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a greater propulsive thrust can be obtained by moving a large mass of air at a comparatively low speed than can be obtained by moving a small mass of air at high speed.

Flexibility: The propjet provides greater flexibility of operation than either the reciprocating engine or the turbojet.

Altitude and Speed: The air transport driven by a propjet obtains its best results when cruising at altitudes above 25,000 feet. At 35,000 feet it can cruise at 420 miles per hour with a 10 percent payload for 3,500 miles. An airplane powered by piston engines could only cruise at 340 miles per hour for the same range and payload, but it must be admitted that for cruising at altitudes below 20,000 feet the airplane driven by the conventional engine would be more satisfactory for ordinary purposes.

At speeds above 425 miles per hour, the turbojet is the best all-around powerplant now available, but it requires an altitude of 35,000 to 40,000 feet.

The primary goal of air line operators is increased speed, especially if it can be obtained without sacrificing comfort, safety, reliability, and economy. It is believed that in the very near future air transports powered with *turbojets* will cruise at a speed of about 450 miles per hour, operate most of the time at an altitude of about 35,000 feet, and schedule flights for ranges of 250 to 1,000 miles. This can be done economically by staggering the stops so that all transports do not make the same stops, thus taking advantage of the economy to be gained by long-range operations.

Improving Business: One of the handicaps suffered by commercial air transportation has been a failure to fill all seats for each flight, or at least enough to pay expenses. Using airplanes designed to carry comparatively small numbers of passengers, 30 to 40 for example, jet-powered transports could operate on a high-speed, high-frequency fixed schedule which would enable the owners to obtain more business, give service to cities not now on the air routes, and probably reduce fares. This kind of flying will take care of about 85 percent of the domestic air-passenger transportation, leaving the remainder to airplanes powered by more conventional engines, although even the slower airplanes flying at lower altitudes and making shorter flights may use some form of jet propulsion.

SUMMARY OF TURBOJET CHARACTERISTICS

Use: High-speed, medium-range fighters; small bombers; and transports.

Maximum Speed Range: 0-1500 miles per hour.

Advantages: High speed, comparatively high altitude, and smooth performance.

Disadvantages: Low thrust horsepower at low speeds and altitudes, range and payload limited by high fuel consumption.

CHAPTER VII

TYPICAL TURBOJET ENGINES IN PRODUCTION

THE PRINCIPAL MANUFACTURERS OF TURBOJET ENGINES

The principal manufacturers of turbojet engines in the United States of America are the Allison Division, General Motors Corporation, Indianapolis 6, Indiana; the Aircraft Gas Turbine Division of the General Electric Co., Cincinnati 15, Ohio; the Pratt & Whitney Aircraft Division of United Aircraft Corporation, East Hartford 8, Connecticut; the Aviation Gas Turbine Division, Westinghouse Electric Corporation, Lester Branch Post Office, Philadelphia 13, Pennsylvania; and the Wright Aeronautical Division of Curtiss-Wright Corporation, Wood-Ridge, New Jersey.

TURBOJET ENGINES MADE BY ALLISON

THE ALLISON J33 TURBOJET ENGINE

General Discussion

The Aircraft Gas Turbine Division of the General Electric Co. developed the I-A turbojet engine, and then the I-16, known to the Air Force as the J31. These early models were followed by the I-40, also called the "G-E Superjet" by the manufacturer, and eventually given the U.S. Air Force designation of J-33. On June 10, 1944, the Lockheed P-80 flew with one J33 engine.

The General Electric Co. engineers favored an axial-flow type of engine for long-range planning, but built the J33 as a centrifugal-type because tools and parts on hand made it easier to get into mass production with that type. At first the engineers aimed at a thrust of 3,000 pounds, then revised their figures to 3,500 pounds, and finally settled on 4,000 pounds, which was the rated thrust for a long time. Currently, the thrust is 5,200 pounds.

This engine has a direct-flow combustion system, as compared to the reverse-flow types, not because of any inherent faults in the reverse-flow system, but merely because the engineers thought that it would result in easier assembly techniques and field servicing, plus a higher overall engine efficiency.

The single-stage compressor is of the double-inlet, multiple-vane centrifugal type. Both air inlets are protected by screens. Compressed air leaving the diffuser enters the combustion chambers through 14 separately cast air adapters. Combustion chambers are of the individual type with removable inner liners. Fuel nozzle assemblies are mounted in each air adapter with the spray nozzle located in the dome section on the upstream end of the combustion chambers. After combustion, the gases are directed at the turbine wheel by the nozzle diaphragm.

The turbine is a single-stage, multiple-"bucket", reaction type. Each bucket is pinned in place to eliminate longitudinal shift and can be individually removed. Diffusion of exhaust gas takes place in a two-piece tailcone assembly which incorporates a "quick-disconnect" type of connection for assembly of the aircraft-

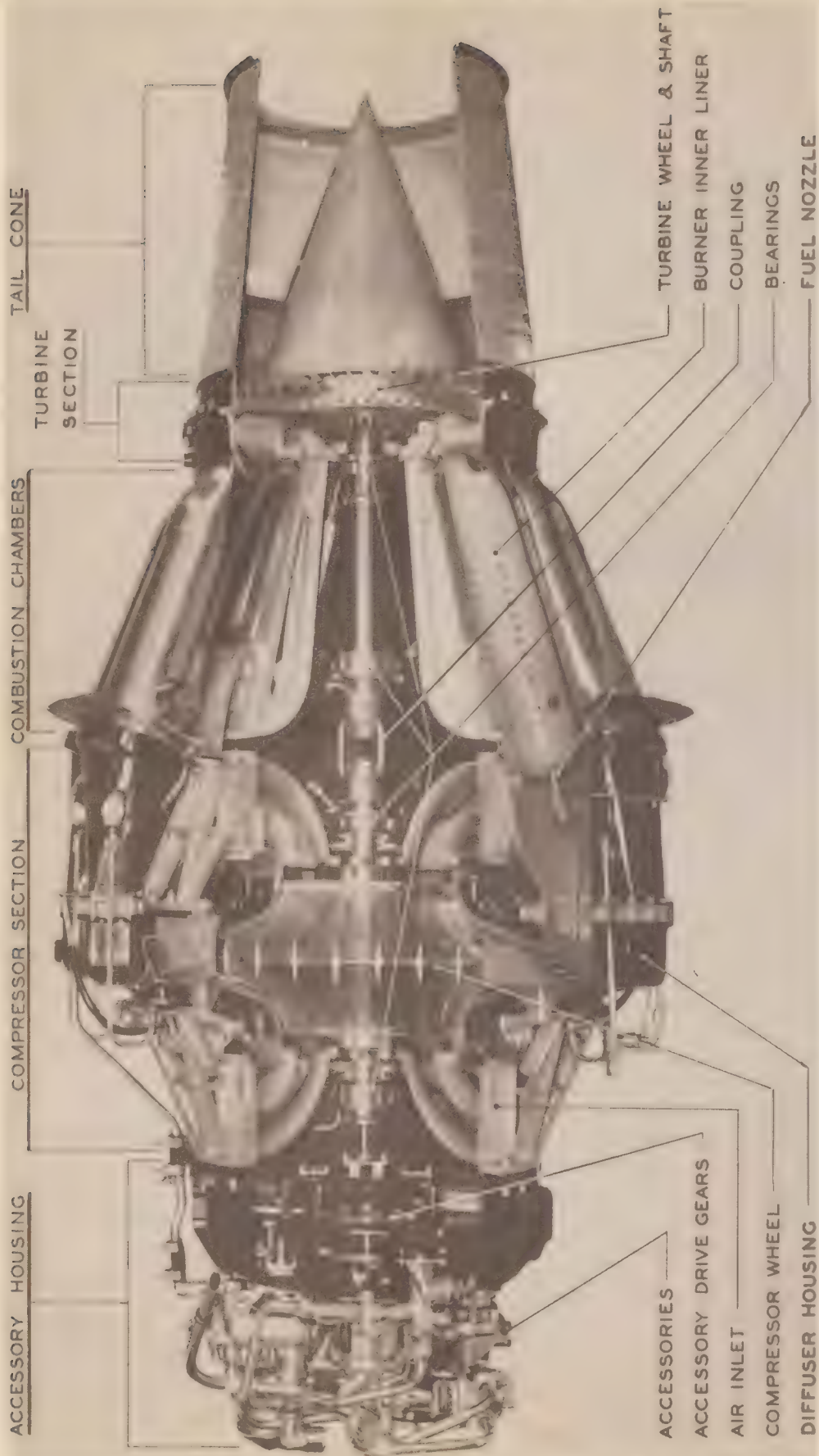


Fig. 1. A cut-away drawing of the Allison J33 turbojet.

TYPICAL TURBOJETTS IN PRODUCTION

supplied tail pipe. This tail-pipe contains the final jet nozzle area and the length is determined by each installation. All engine-driven accessories and fuel controls are mounted on the forward end of the engine.

Fig. 1 is a cutaway drawing of the J33. Fig. 2 is a partially cut-away illustration of the J33 turbojet engine installed in the Lockheed F-80 "Shooting Star". It should be emphasized that although the J33 was originally produced by the General Electric Co., the Allison Division of the General Motors Corporation has had the sole responsibility for production and engineering since October, 1945.

This engine currently is allowed 1,200 hours between overhauls and as additional service experience is accumulated, the time between overhauls is being extended.



Fig. 2. A partially cut-away illustration of the J33 turbojet installed in the Lockheed F-80 Shooting Star.

J33 Engine Performance Data

Further development is being carried on with this engine because a centrifugal-type jet engine with single-stage compressor can be manufactured with productibility at less cost per pound of thrust than any other type of jet engine now in production. Also, it has a very high power per pound of engine weight. The combination of these two factors makes the J33 an important consideration not only in aircraft performance but in expendable type guided missiles.

The J33 engine also has served as a basic design model for many jet engine developments which are being applied to other engines, principally the J35. Engines with greatly increased ratings are under development, but, as of the date of publication, the current production model (J33-A-35) is rated as follows:

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Rating (takeoff, static, w/a inj.)	5,400 lb. thrust 11750 rpm/sea level
Rating (takeoff, static)	4,600 lb. thrust 11750 rpm/sea level
Rating (normal, static)	3,900 lb. thrust/11250 rpm/sea level
Rating (90% normal, static)	3,510 lb. thrust/10900 rpm/sea level
Compression ratio:	5.1: 1
Air mass flow:	90 lb./sec./11750 rpm/sea level
Rated exhaust gas temp.:	1,340 deg. F.
Fuel:	Mil-F-5634, Grade JP-3 or Mil-F-5572 Grade 100/130
Fuel consumption (cruising):	1.12 lb./lb. thrust/hr.
Oil scavange pump:	Gear type
Water injection:	Optional
Ignition system:	2 ignitor plubs, transformers, shielded
Diameter:	50.5 in.
Length (w/tail cone):	107.6 in.
Weight:	1,820 lbs.
Frontal area:	13.9 sq.ft

THE ALLISON J35 TURBOJET ENGINE

General Discussion

During the development of the J33 turbojet engine, the General Electric Co. went ahead with its development of the axial-flow type of jet engine. The centrifugal-flow types, as exemplified by the I-series engines, such as the General Electric Co.'s I-A, I-16 (J31), and I-40 (J33), were relatively light in weight, easy to install and service, and operating successfully. However, the theory of compressor design seemed to indicate that they were reaching their limit of pressure-ratio possible in a single-stage type of compressor.

The axial-flow compressor is inherently more efficient and makes possible higher pressure ratios, resulting in higher thrust output with lower specific fuel consumption. Therefore, the General Electric Co. TG-180 turbojet engine, later given the Air Force designation of J35, was developed. It is an axial-flow turbojet with multi-stage compressor and single-stage turbine. The air enters the front, goes through eleven stages of compression to eight burners or combustion chambers, through the 126-blade stainless-steel turbine wheel, and out through the tail cone. It has a relatively small frontal area and a streamlined shape.

The J35 was flown in February, 1946, in the Republic P-84, and was released for production to Chevrolet, and later to the Allison Division of the General Motors Corporation. It has been installed in many types of military airplanes, including fighters, bombers, transonic research aircraft, and others.

Main Bearings

Fig. 3 shows the air flow and combustion system; furthermore, this figure shows the four main rotor bearings. No. 1 is a roller bearing mounted on the forward end of the compressor shaft. No. 2 is a ball thrust bearing mounted on the elongated hub of the No. 1 compressor rotor wheel. No. 3 is a roller damper bearing mounted in the aft (rear) frame. No. 4 is a roller bearing mounted on the rear end of the turbine wheel shaft.

AIR FLOW AND COMBUSTION

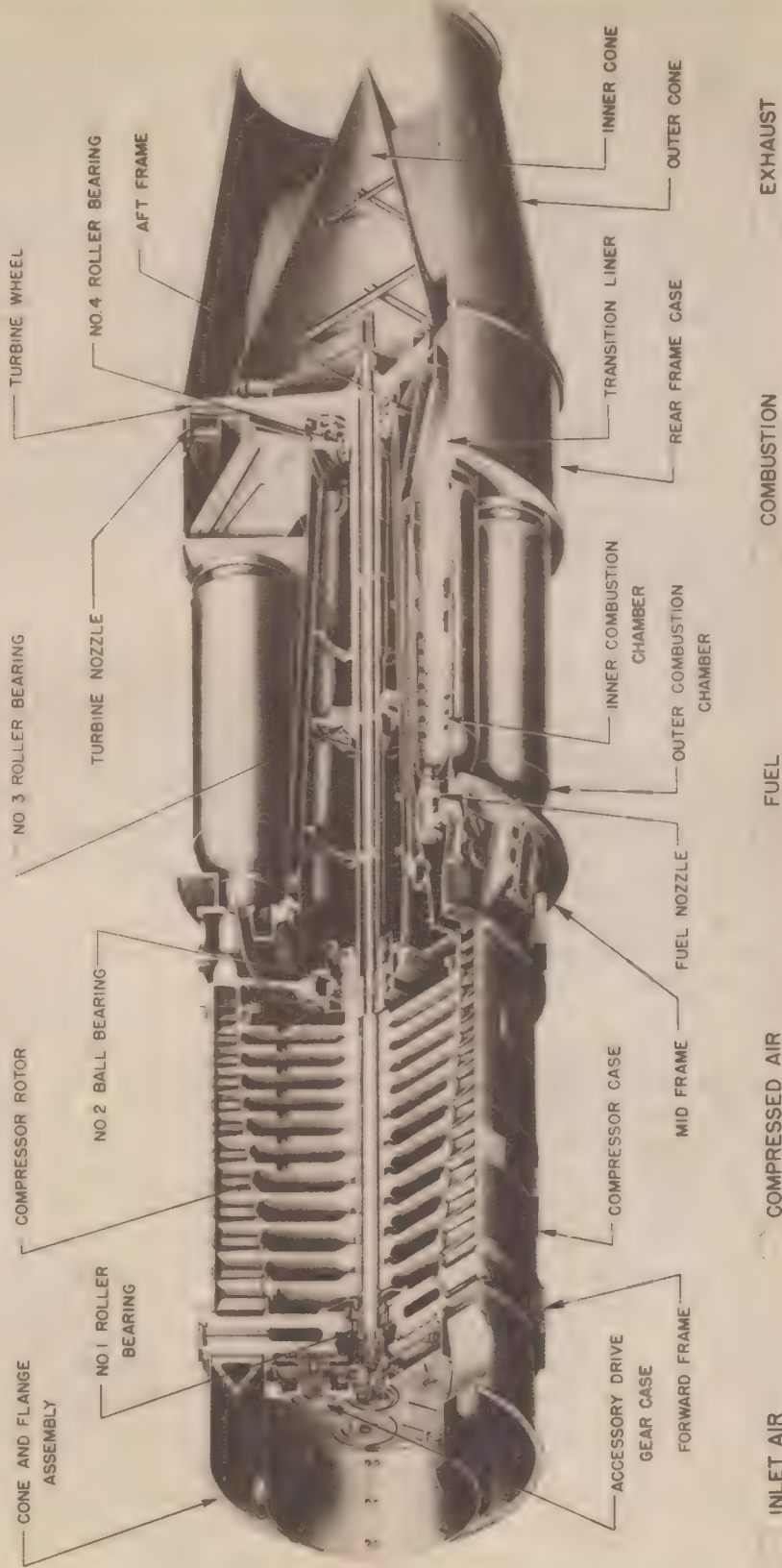


Fig. 3. Air flow and combustion system of the Allison J35.

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Accessory Drive Assembly

The accessory drive assembly is mounted on the front end of the engine. It is made up of a magnesium alloy casing assembly, the gear trains which drive the accessories, the ball bearings which carry the load of the accessory drives, and a pinion and drive shaft assembly. Provision is made for mounting the driven accessories on the forward face of the accessory casing assembly. Power for the driven accessories is obtained by means of a splined coupling which is mounted on the front end of the compressor rotor shaft. The torque (turning effect) is transmitted through this splined coupling to the pinion and drive shaft assembly which is mounted in the center of the accessory drive assembly.

The accessories which are mounted on and driven by the accessory drive assembly include the Bendix fuel control, tachometer generator, dual fuel pump, lubrication pump, hydraulic pump, and the starter-generator.

Non-driven accessories which, because of their function, are also mounted on the accessory drive assembly are all integral parts of either the fuel system or the lubrication system and include the emergency pressure switch, emergency fuel control, high pressure fuel filter for main fuel system, double check valve (fuel system), high pressure fuel filter for emergency fuel system, oil filter, and fuel flowmeter.

Additional non-driven accessories attached to the compressor unit assembly include the oil filter, drip valve, ignition transformers, and electrical junction box.

Compressor Unit Assembly

The compressor unit assembly is made up of an eleven-stage axial flow compressor rotor assembly, a thirteen-stage compressor casing assembly, which is horizontally divided into upper and lower casing assemblies, a forward frame assembly, and a mid-frame assembly.

The compressor rotor assembly is composed of eleven wheel assemblies mounted on a steel alloy shaft. The first eight of the wheels are aluminum, and the other three are steel. Each of the wheels is equipped with a continuous row of steel blades dovetailed into the rim. The wheels are progressively larger in diameter from front to rear, and the blades are progressively shorter from front to rear. This combination provides a unit of constant diameter.

The compressor rotor is mounted on a roller bearing (No. 1 Main) in the forward frame and on a ball thrust bearing (No. 2 Main) in the mid-frame. The eleventh (steel) wheel has an elongated rear hub which is hollow and internally splined. This spline, when the engine is assembled, mates with the externally splined turbine shaft, thereby providing means of torque transmission.

The compressor casing assembly upper and lower halves are identical except for small differences in machining on the outer surface. They are magnesium alloy castings and have identical serial numbers. These must remain together as a unit. The thirteen rows of steel stator vanes are progressively shorter from front to rear. Twelve of the rows are dovetailed into rings which mount in grooves machined in the inner surface of the cases. The other row, which serves as the entrance vanes, is mounted as an assembly to the rear side of the forward frame.

The forward frame assembly is essentially the forward structural member of the engine. It is a magnesium alloy casting which provides mounting for the

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forward end of the compressor case and compressor rotor, and provides front mounting pads for aircraft installation. It also provides for mounting the accessory drive assembly and the air guide section of the engine.

The mid-frame assembly is made from an aluminum alloy casting. It is the middle structural member of the engine, being equipped with mounting pads which are used for making the main attachment of the engine to the aircraft. Eight air passages, which are an integral part of the casting, serve to conduct the compressed air from the compressor outlet to the eight combustion chambers. In addition, the mid-frame also mounts the eight fuel nozzles, the No. 2 ball thrust bearing, the oil scavenge pump for the Nos. 2, 3, and 4 bearings, the front end of the combination chambers, the aft (rear) frame assembly, and contains a cabin heating and pressurizing manifold.

Turbine Stator Assembly

The turbine stator assembly consists primarily of the aft frame assembly, turbine nozzle assembly, turbine casing assembly, eight combustion chambers, and eight transition liners.

The aft frame assembly is essentially the basic foundation for the rear section of the engine. It is a conical-shaped, sheet metal, welded assembly which provides a mounting flange at the front for attachment to the mid-frame and one at the rear for mounting the turbine nozzle. The aft frame incorporates monocoque channels within the cone to provide the rigidity and strength required. At about three-fourths the distance to the rear of the assembly, a bulkhead (wall) with eight flanged holes is incorporated for combustion chamber mounting. No. 3 main rotor bearing assembly and No. 4 main rotor bearing housing and outer race are mounted in this part of the engine. Scavenging of lubricating oil is accomplished by a scavenge pump mounted in the mid-frame.

The turbine nozzle assembly is a stainless steel welded assembly consisting of outer and inner rings between which are welded 72 airfoiled (streamlined) hollow vanes. These vanes, because of their relation to each other and to the angularity of installation in the rings, provide a directional nozzle for the flow of gases against the buckets of the turbine wheel.

The eight combustion chambers are mounted circumferentially around the aft frame and consist of a cylindrical outer chamber into which is fitted a removable inner chamber. A fuel nozzle installed in the forward end of each combustion chamber is responsible for the injection of fuel into the inner chamber, where it is mixed with air and burned. The outer combustion chambers are joined to each other near their forward ends by bellows-type inter-connectors into which are inserted inner cross-over tubes that connect the inner combustion chamber. This makes it possible for pressures to equalize and combustion to spread from one chamber to another.

Between the combustion chamber outlets at the bulkhead and the turbine nozzle are eight transition liners that conduct the gases from the chambers to the entire annulus (ring-like structure) of the nozzle. The turbine casing surrounds and encloses the transition liners.

Turbine Wheel Assembly

The turbine wheel assembly consists of a hollow shaft, the wheel rim, 95 buckets, No. 3 bearing inner race, and No. 4 bearing. The shaft splines directly

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into the compressor rotor eleventh stage wheel and the entire assembly is held in position by the turbine shaft bolt, which is threaded directly into the end of the compressor rotor and extends through the hollow turbine wheel shaft.

Exhaust Cone Assembly

The exhaust cone assembly consists of an outer cone and an inner cone. The inner cone is so designed and mounted within the outer cone that a duct of relative constant volume is formed for conducting the gases from the turbine wheel to the tailpipe. Air for cooling the rear side of the turbine wheel is conducted into the exhaust cone assembly by one air line which is flange-mounted to the outer cone. An air passage through a strut support into the interior of the inner cone directs this air against the turbine wheel.

Engine Lubrication System

Fig. 4 is a schematic diagram of the engine lubrication system. The J35 has a dry sump lubrication system which is supplied with oil from an aircraft-furnished tank. Oil supplied from the tank enters into the pressure element of the lubrication pump, which is mounted on the accessory case at the 5:30 o'clock position (assuming that 12 o'clock is at the top). The oil pressure is regulated by a pressure relief valve (part of the oil pump), hence the proper flow is maintained for all conditions of operation.

After the oil is pressurized, it passes from the pump to a "T" fitting where it divides and takes two main paths: one path is to the accessory housing and the other is to the Nos. 2, 3, and 4 main bearings. The oil that flows to the accessory housing passes through a filter and a check valve (mounted on the accessory housing) and is then divided into two paths.

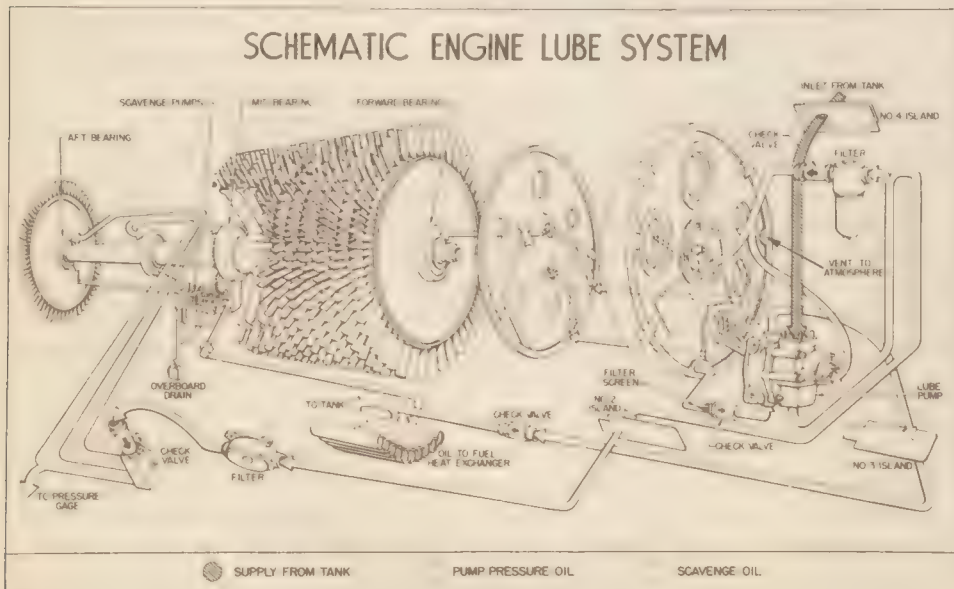


Fig. 4. A schematic diagram of the J35 engine lubrication system.

TYPICAL TURBOJETS IN PRODUCTION

One of these paths directs the oil to the bearing cap, and the other sends the oil to the oil pump. Oil passing into the bearing cap supplies oil through drilled passages to the internal splines of the pinion drive shaft, the fuel regulator, and the starter-generator front drive bearing. The oil returned to the pump moves through a drilled passage in the pump body. At the mounting flange of the pump, this passage mates with three drilled passages in the accessory case. These terminate at three nozzles which provide the lubrication for the No. 1 main bearing, and the bearings and gears of the accessory housing.

The oil used to lubricate the Nos. 2, 3, and 4 main bearings passes through a filter which is mounted on the compressor case. It then passes through a check valve and into a junction block from which three individual take-offs provide the lubrication for the bearings. A "T" fitting from one of these lines provides the sensing for the lubrication pressure indication in the cockpit of the airplane.

The scavenge element of the main lubrication pump returns all of the oil from the accessory housing and the No. 1 bearing to the aircraft supply tank. Two scavenge pumps are mounted in the midframe, and they scavenge oil from the Nos. 2, 3, and 4 main bearings, returning the oil to the heat exchanger (mounted on the compressor casing). The main fuel supply to the engine is directed through the heat exchanger and cools the oil before it is returned to the aircraft supply tank.

Engine Fuel System

Fig. 5 is a schematic diagram of the engine fuel system. Fuel from the aircraft supply is furnished by a boost pump to the inlet of the dual fuel pump. Fuel flow from the two outlets (main and emergency) is directed through the main filter to the main fuel control, and through the emergency filter to the emergency fuel control.

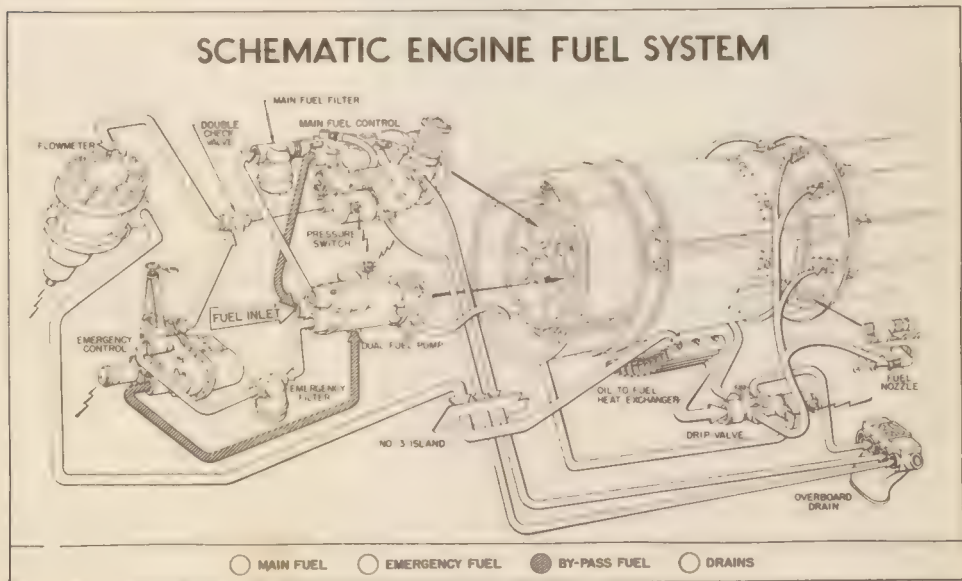


Fig. 5. A schematic diagram of the J35 engine fuel system.

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The output of the dual fuel pump (either main or emergency) is always in excess of engine requirements. By-pass valves are required to take care of this condition and they are built into the main and emergency fuel controls. All fuel that is not required by the engine is by-passed into the dual pump.

During normal operation, fuel metered by the main control supplies the engine. The main control also includes a cut-off valve, which provides the means for completely stopping fuel flow to the engine at shut-down.

Functions of the Main Fuel Control

The main fuel control is a metering device which accomplishes the following functions:

1. It maintains a pre-selected, constant r.p.m., compensating for factors affecting air density.
2. It limits the minimum engine r.p.m.
3. It automatically meters the fuel to limit the exhaust gas temperature during acceleration and deceleration.
4. It allows the engine r.p.m. to increase with altitude, thus eliminating "flame-outs", and maintaining the acceleration rate from idle speed to full r.p.m.

Emergency Control

The emergency control by-passes all emergency fuel during normal operation. This is accomplished through a by-pass valve that is spring-loaded to the open position. If the emergency position is required, the by-pass valve is closed by a solenoid (electromagnet), allowing the emergency fuel control to meter fuel for engine needs. The control also contains a combination cut-off and throttle valve. This valve operates in direct relationship with the cut-off valve of the main fuel regulator, since both are controlled through the same linkage.

Electrical System

When the turbojet is started, the speed must be mechanically increased until the velocity is enough to supply a flow of air for the mixture of fuel and air which is ignited to produce combustion.

The turbine and compressor are not very efficient at the low speed and low compressor discharge pressure prevailing at the beginning of engine operation. Even after the burning begins, the starting motor must be used to help accelerate the unit to the speed at which the engine speed is self-sustaining.

When the engine speed and the compressor discharge pressure have increased enough, the turbine and compressor efficiencies become great enough for the engine to operate thereafter without assistance from the starting motor, which is then electrically disconnected.

Starting Units

The starting units are:

(1) *The starter generator.* This is a direct-coupled, 24-volt, direct-current unit, running at about the same speed as the engine. As a starter, it can develop about 25 horsepower for a short period. Under engine-operating conditions, it is a 400-ampere, 24-volt, d.c. generator which is used for generating aircraft electrical power.

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(2) *Ignition system.* The ignition system includes two transformers, the necessary electrical wiring, and two spark plugs. The transformers receive 115 volt, a.c. 400 cycle power from the aircraft installation, and in turn furnish about 15,000 volts to the igniter plugs. This voltage is supplied through high-tension leads to the igniter plugs located in Nos. 1 and 5 combustion chambers. The ignition system is used only during the starting procedure. The ignition in the other six chambers is obtained by flame travel through the cross-ignition tubes.

How the Engine Is Started

The engine is started by energizing (turning the current on) the starting and ignition circuits, thus accelerating the engine to about 600 to 800 r.p.m., which is the firing speed. When the firing speed is reached, the throttle is placed in the idle position, the engine fires and then automatically accelerates to the idle r.p.m.

When engine speed reaches about 1,800 r.p.m., it becomes self-sustaining, and the starter control cuts out the starter circuit. At about 3,000 r.p.m., the generator voltage output is enough to close the reverse current relay which connects the generator to the aircraft electrical system.

It is not necessary to warm up the engine. It may be accelerated immediately to full thrust. The total time required to reach take-off thrust from the moment that the starter circuit is energized is about 50 seconds. The ignition is required only during the few seconds needed to ignite the fuel. The circuit is then de-energized (current is shut off), although it is completely radio-shielded to provide for operation without interfering with the radio or radar systems on the airplane.

The ram pressure obtained by the forward speed of the airplane causes the engine to "windmill" if it is not operated while the aircraft is moving at high speed. The velocity of the engine while windmilling is enough to start the turbojet in flight by energizing the ignition circuit and advancing the throttle lever, without energizing the starter.

The gas temperature is indicated in the cockpit by means of connections to thermocouples installed in the exhaust system.

J35-A-29 Engine Performance Data

Rating (take-off, static):	5,600 lbs. thrust/8,000 r.p.m./sea level
Rating (normal, static):	4,900 lbs. thrust/7,650 r.p.m./sea level
Rating (cruising, static):	4,410 lbs. thrust/7,650 r.p.m./sea level
Compression ratio:	5.0:1
Air mass flow:	89 lb./sec./7,770 r.p.m./sea level
Exhaust gas temperature:	1,340° after turbine/sea level
Electrical system:	Shielded harness, 2 ignitor plugs, 2 transformers
Fuel consumption, gasoline, cruising:	1.07 lb./thrust/hr.
Diameter:	37.0 in.
Length (w/tail tube):	146.0 in.
Weight:	2,305 lb.

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Frontal area:	7.4 sq. ft.
Allowable time between overhauls:	400 hours
Allowable time between overhauls with minor repairs:	800 hours

THE ALLISON J71 TURBOJET ENGINE

The Allison J71 turbojet engine is a 16-stage, axial-flow, turbojet engine with a 3-stage turbine and ten combustion chambers. It has an electro-mechanical type control system, with automatic acceleration and starting controls. The fuel system is of the single fuel manifold type. There is a dry-sump lubrication system.

The engine is 172 inches long, it has a frontal area of 7.5 square feet, and it weighs 4,100 pounds. The static, dry thrust at take-off is more than 10,000 pounds. for the J71-A-1 model. The Navy J71-A-2 model, equipped with an afterburner, has a static dry thrust at take-off of 14,000 pounds.

TURBOJET ENGINES MADE BY GENERAL ELECTRIC CO.

GENERAL ELECTRIC J47 TURBOJET ENGINE

The General Electric J47 turbojet engine, known within the General Electric Co. as the TG-190, includes many improvements over earlier models.

It has a 12-stage axial compressor, 8 combustion chambers, and a single-stage turbine. Hydraulic power controls the path of the fuel flow instead of using the displacement of the fuel pump, hence the pump operates at constant speed, causes less trouble, and can be made with a simpler design.

The older G.E. J35 has a method of lubrication called "oil mist", wherein a mixture of air and oil is sprayed on the main bearings in a fine spray. The hot oil is then scavenged overboard during flight. However, in the J47, there is a recirculatory system, requiring a smaller supply of oil to be carried on the airplane and better heat transfer away from the regions of the main bearings. Thus, bearing temperatures are no longer a limitation on the operation of the unit, since the oil mist type of system and its temperature problems are not present.

Fig. 6 shows the General Electric family of turbojet engines, including the early I-A, I-16, J33, the J35, the J47-D, the J47-E, and the J73-1. The J33 and the J35 are now manufactured by the Allison Division of General Motors.

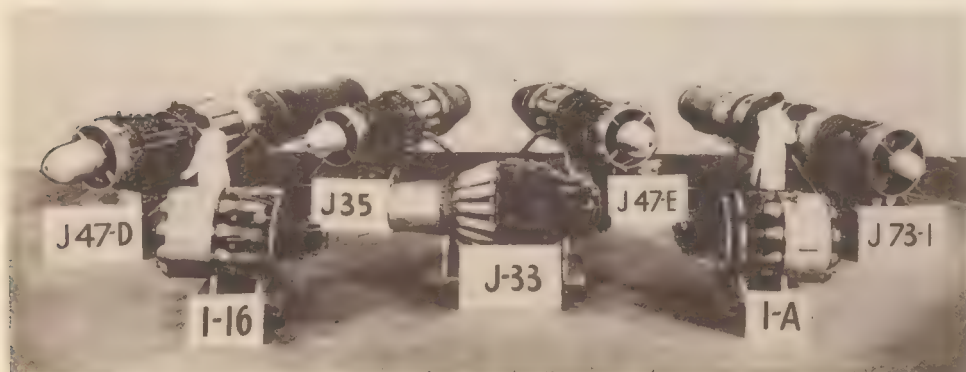


Fig. 6. The General Electric family of turbojet engines.

TYPICAL TURBOJETTS IN PRODUCTION

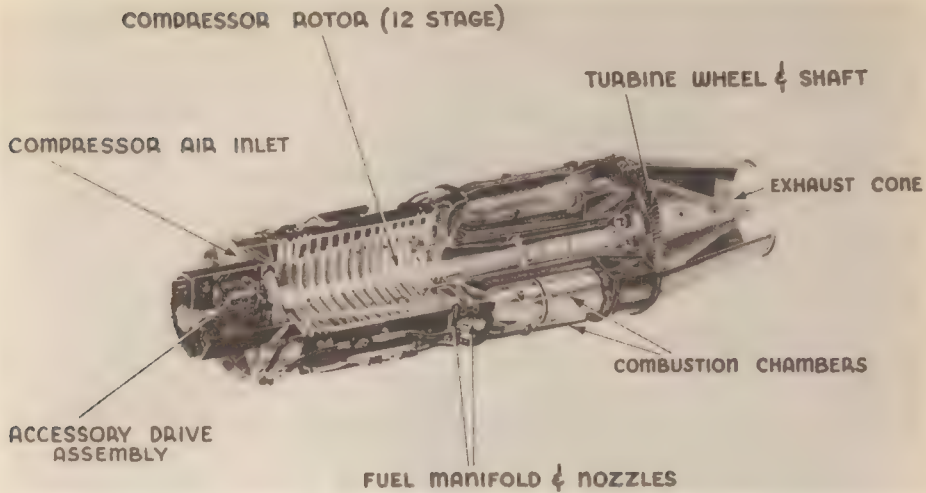


Fig. 7. A cutaway drawing of the General Electric J47 turbojet engine.

Fig. 7 is a cutaway drawing of the General Electric Co. J47 turbojet engine. The accessory drive assembly, compressor air inlet, compressor rotor (12 stage), turbine wheel and shaft, exhaust cone, combustion chamber, and fuel manifold and nozzles are labelled.

Fig. 8 shows the principal parts and units of a G.E. turbojet engine. Air enters the front (left) passing around the accessory equipment, through the forward frame, and into a 12-stage, axial-flow compressor. High pressure is built up by the compressor. Air passes through the midframe, and into eight combustion chambers, where fuel is injected by atomizers. By burning the fuel, the combustion products expand at tremendous velocity through a nozzle diaphragm and turbine wheel. Power from the turbine drives the compressor and, through gear reduction, the accessories. Exhaust from the turbine passes out through the exhaust cone and provides the jet thrust (in excess of 5,200 pounds) that drives the airplane.

Late models of the J47 series have such features as good re-starting characteristics at high altitudes, all-weather operation, and the inclusion of less strategic materials, plus higher performance in power output and fuel consumption. A compression ratio of 5:1 and increased air flow through the engine make these performance figures possible. When "augmentation" ("beefed up" power) during take-off conditions is desired, especially when the airframe is heavy and it has its least momentum, the injection of a mixture of water and alcohol provides the necessary stimulation.

Fig. 9 shows a mechanic adjusting the compressor stator of the J47. Each stator has hundreds of blades. The *rotor*, which is the rotating part of the compressor, also has hundreds of blades. The use of fabricated stator blades, instead of forged blades used on earlier turbojet engines, results in a tremendous saving in money.

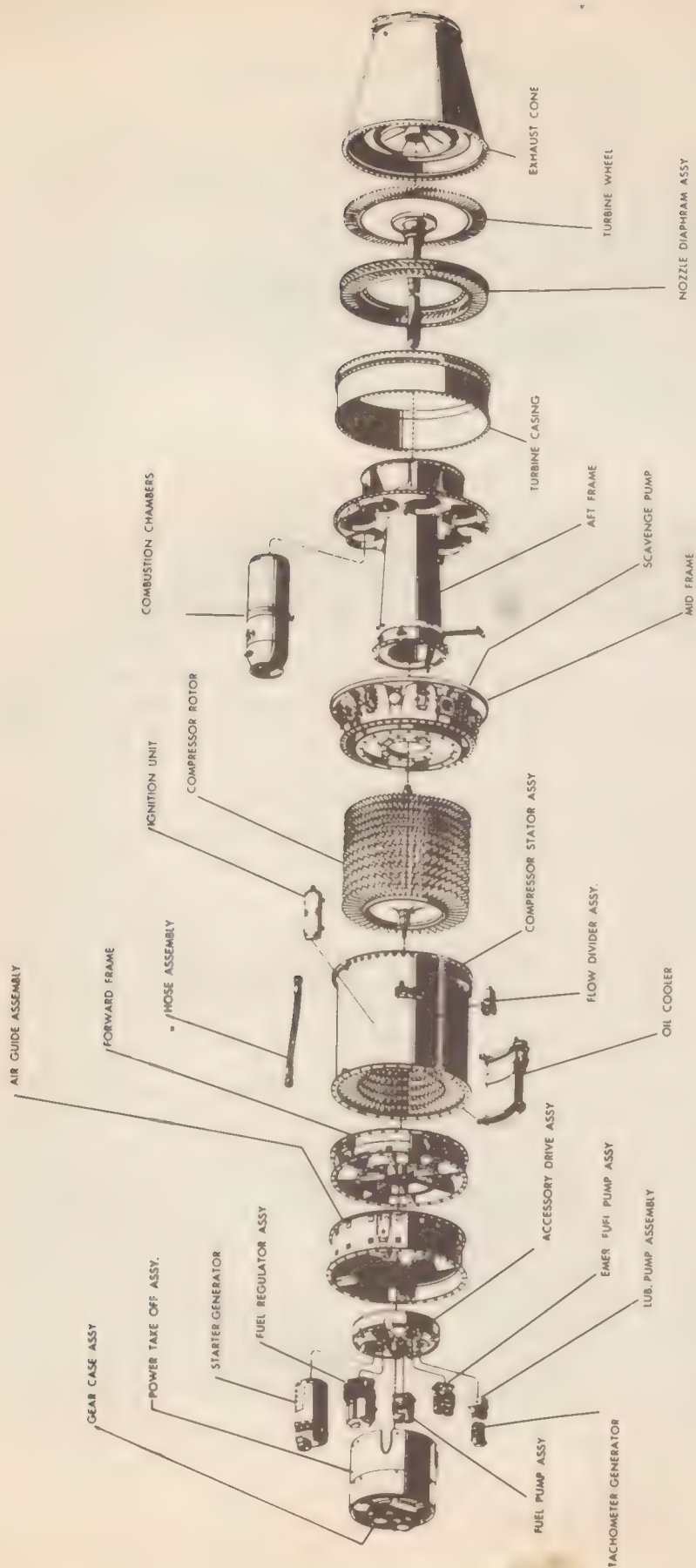


Fig. 8. The principal units and parts of a G. E. turbojet engine.

TYPICAL TURBOJETS IN PRODUCTION

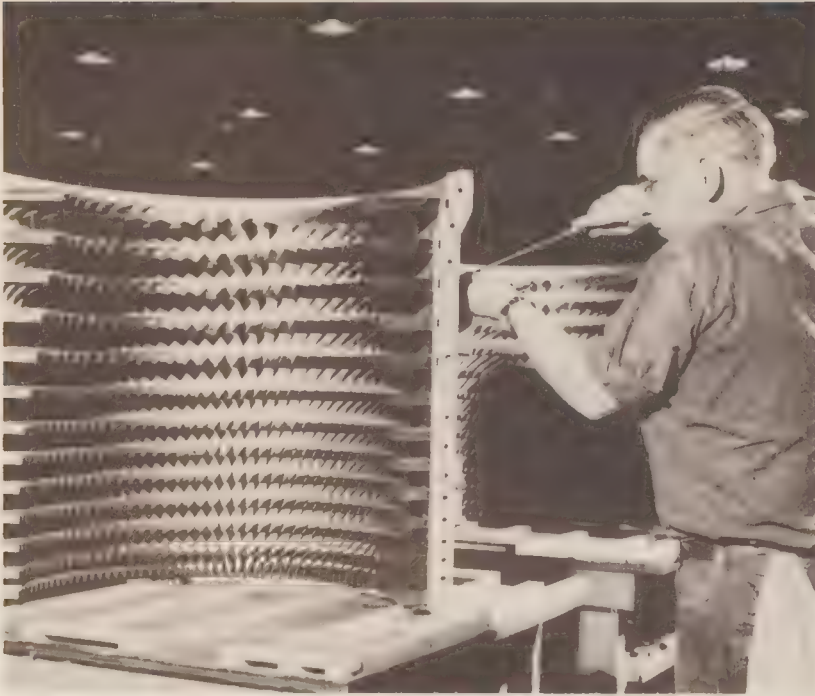


Fig. 9. A mechanic adjusting the compressor stator of the J47.

The General Electric J47 series of turbojet engines are basically similar, but differ within the series. There is the J47 C series, the J47 D series with the afterburner, and the J47 E series, the latter including Models J47-GE-23 and J47-GE-27.

As an example of changes made as engine design progresses, the J47-GE-23, is an all-weather, axial-flow, turbojet engine having a thrust rating at take-off of more than 5,800 pounds (dry). The engine has a "hot nose", that is, hot air is bled from the compressor to hollow nose parts, which provides anti-icing protection. Also, there is a special ignition system which makes possible high altitude starting. Water injection is available for thrust augmentation, and this gives a thrust rating of more than 6,700 pounds at take-off.

THE GENERAL ELECTRIC J73 TURBOJET ENGINE

The General Electric J73 turbojet engine, shown at the right in Fig. 6, is a 12-stage, axial compressor, 10-combustion-chamber, 2-stage, turbine-type engine. The control system is of the electro-hydraulic type, with automatic acceleration and starting controls. A dual fuel manifold system is used. The lubrication system is of the dry sump type.

The engine is 200 inches long, has a frontal diameter of 39.5 inches, and a frontal area of 8.5 square feet. The weight is 3,600 pounds. It has a static, dry, thrust at take-off of more than 9,000 pounds. The J73-GE-5 is similar to the J73-GE-1 and J73-GE-3, except that it has an afterburner, and a dry, static thrust at take-off of more than 12,000 pounds.

JET AIRCRAFT SIMPLIFIED

TURBOJET ENGINES MADE BY PRATT & WHITNEY

PRATT & WHITNEY J42 TURBOJET ENGINE

The Pratt & Whitney J42 turbojet engine, also known as the Pratt & Whitney Turbo-Wasp JT-6, is a single-stage, centrifugal-type turbojet engine with nine combustion chambers and a single-stage turbine. The control system is of the hydro-mechanical type with automatic acceleration and starting controls. There is a dual fuel manifold. The lubricants are pressure-fed to the main bearings.

Fig. 10 illustrates the J42-P-4, J42-P-6, and JT 6B models. Important units and parts are labelled. The diameter is 49.5 inches, the engine is 103.2 inches long, it has a frontal area of 13.4 square feet, and it weighs 1,729 pounds. The static dry thrust at take-off is more than 5,000 pounds and the static wet thrust at take-off is more than 5,750 pounds.

This turbojet engine is manufactured under license from Rolls-Royce, Ltd., of Great Britain.

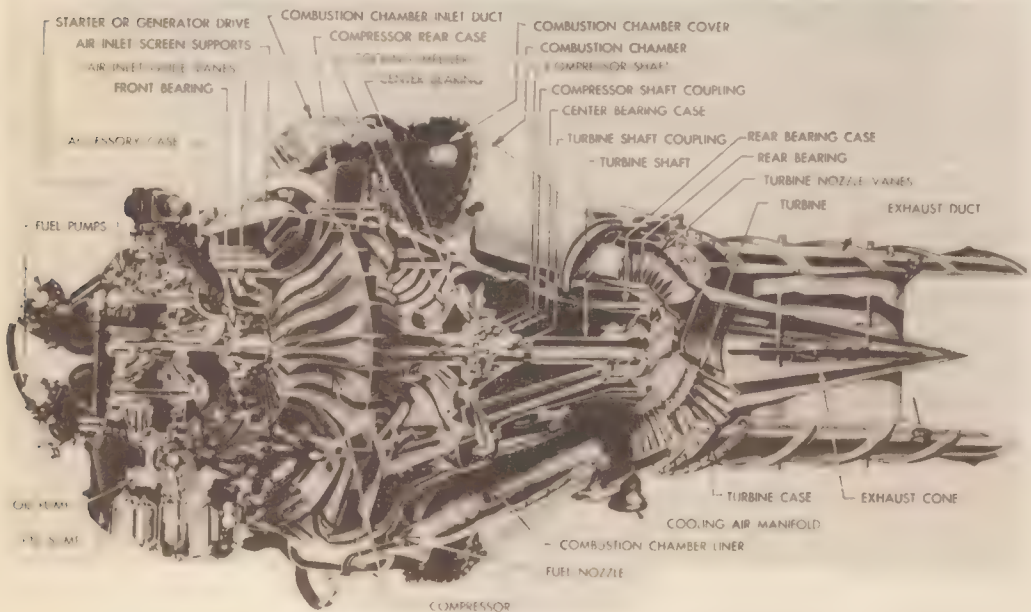


Fig. 10. Pratt & Whitney J42 turbojet engine.

PRATT & WHITNEY J48 TURBOJET ENGINE

The Pratt & Whitney J48 turbojet engine is a single-stage turbojet engine of the centrifugal type with nine combustion chambers and a single-stage turbine. It has a dry-sump type lubrication system, a dual fuel manifold system, and a hydro-mechanical type control system. The diameter is 50 inches, the length is

TYPICAL TURBOJETS IN PRODUCTION

106.7 inches, the frontal area is 13.6 square feet, and the weight is 2,000 pounds. The static, dry thrust at take-off is more than 6,250 pounds and the static wet thrust at take-off is more than 7,000 pounds. This turbojet engine is manufactured under a license from Rolls-Royce, Ltd., of Great Britain.

PRATT & WHITNEY J48 TURBOJET ENGINE WITH AFTERBURNER

The Pratt & Whitney J48 Turbojet Engine with afterburner is illustrated in Fig. 11. It is known as the Pratt & Whitney J48-P-5, and also as the Pratt & Whitney Turbo-Wasp JT-7. It resembles the J48 previously discussed except that it has an afterburner, the length is 226 inches, and the weight is 2,800 pounds. The dry, static thrust at take-off is more than 8,300 pounds.

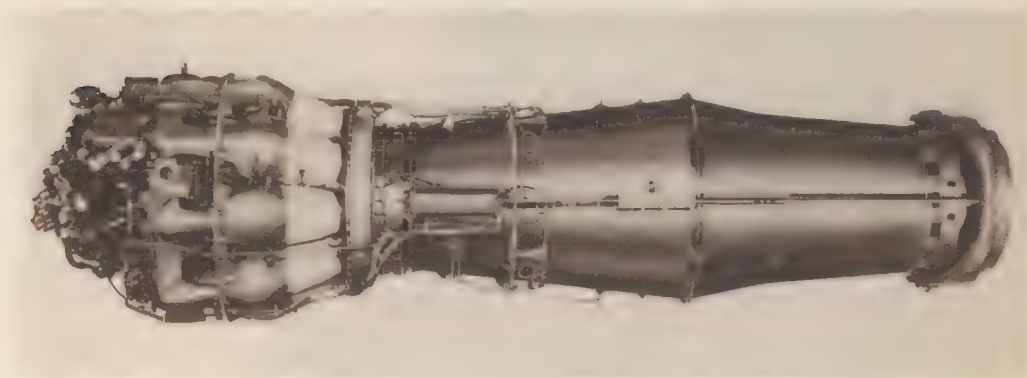
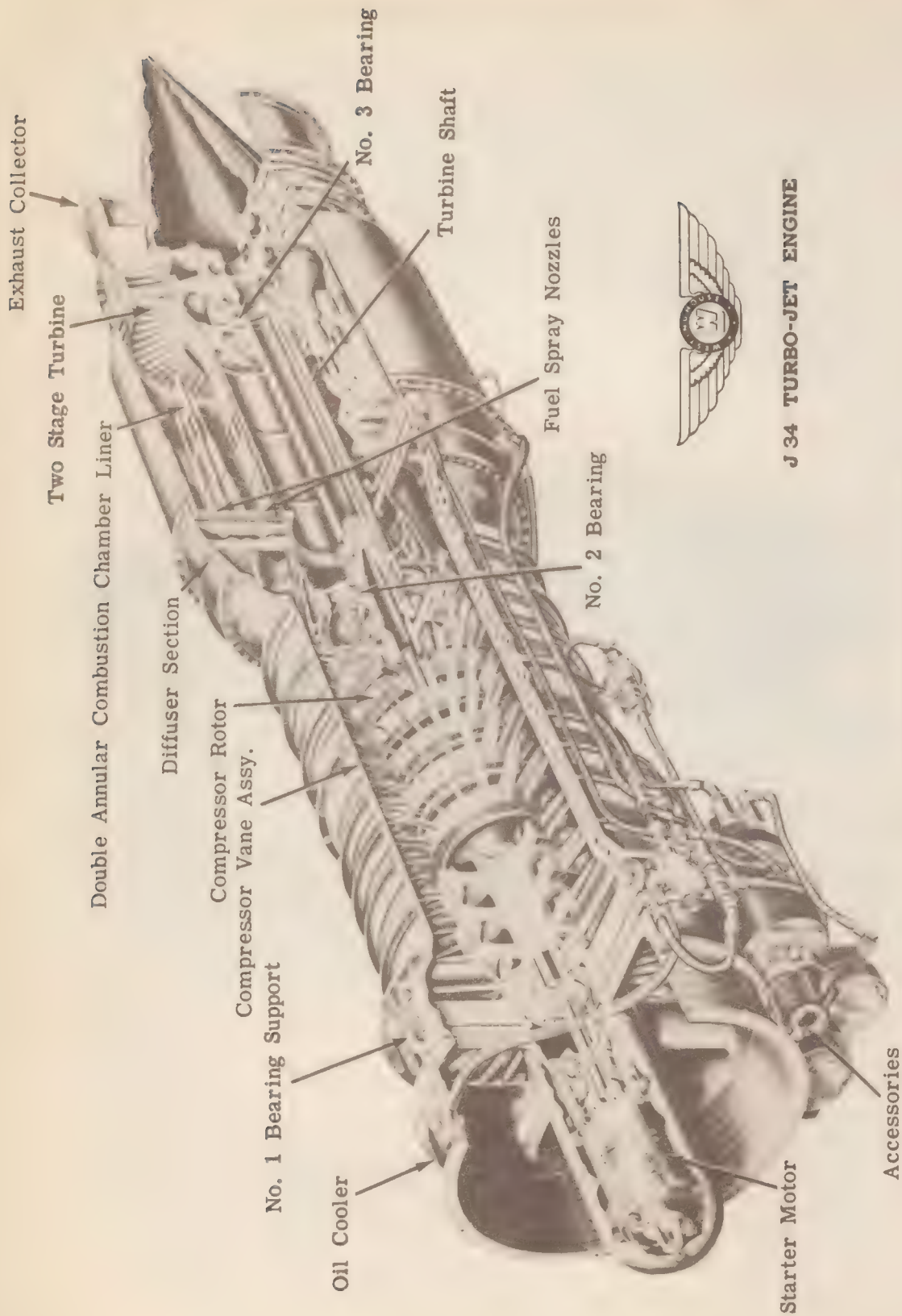


Fig. 11. Pratt & Whitney J48 turbojet engine with afterburner.

PRATT & WHITNEY J57 TURBOJET ENGINE

The newest and most powerful engine currently being developed by Pratt & Whitney is their big axial-flow turbojet engine designated as the J57. For security reasons, it is impossible to give specific power ratings for this engine; however, it can be reported that it has exceptional fuel economy. The Air Force's opinion of the engine is expressed by the fact that it has been selected to power the eight-engined Boeing B-52, the first big intercontinental jet bomber to be ordered into production. The engine is also flying in Convair's B-60, which is the eight-engined swept-winged jet development of the B-36; and furthermore, the J57 is being used in North American's F-100, the "Super Sabre".



J 34 TURBO-JET ENGINE

Fig. 12. The Westinghouse J34 turbojet engine.

TYPICAL TURBOJET ENGINES IN PRODUCTION

TURBOJET ENGINES MADE BY THE WESTINGHOUSE ELECTRIC CORPORATION

THE WESTINGHOUSE J34 TURBOJET ENGINE

General Discussion of the J34 Turbojet

The J34 turbojet, illustrated in Fig. 12, is the third of a series of turbojet engines developed by the Westinghouse Electric Corporation for the U. S. Navy Bureau of Aeronautics. Like its two predecessors, it is of a straight-through, axial flow design, consisting of an axial flow compressor, combustion chamber, turbine, and exhaust jet arranged in such a manner as to eliminate the inherent losses incurred in severely turning the air stream.

Fig. 12 shows many of the mechanical features of the engine. Air passes through the annular space between the oil cooler and the dome covering the electric starter motor. The oil cooler is bolted to the No. 1 bearing support which is a magnesium casting with four radial struts which support the front end of the compressor rotor. The stationary compressor vane assemblies are retained in a cast aluminum housing. The compressed air leaves the outlet end of the compressor and passes through the diffuser section in which fuel is added on its way to the combustion chamber. Burning takes place inside a double annular combustion-chamber liner. The products of combustion pass through the two-stage turbine and the exhaust collector, thence to the exhaust nozzle which is attached to the rear of the exhaust collector but is not shown on Fig. 3. The turbine shaft transmits power from the turbine necessary to drive the compressor and the engine-driven accessories.

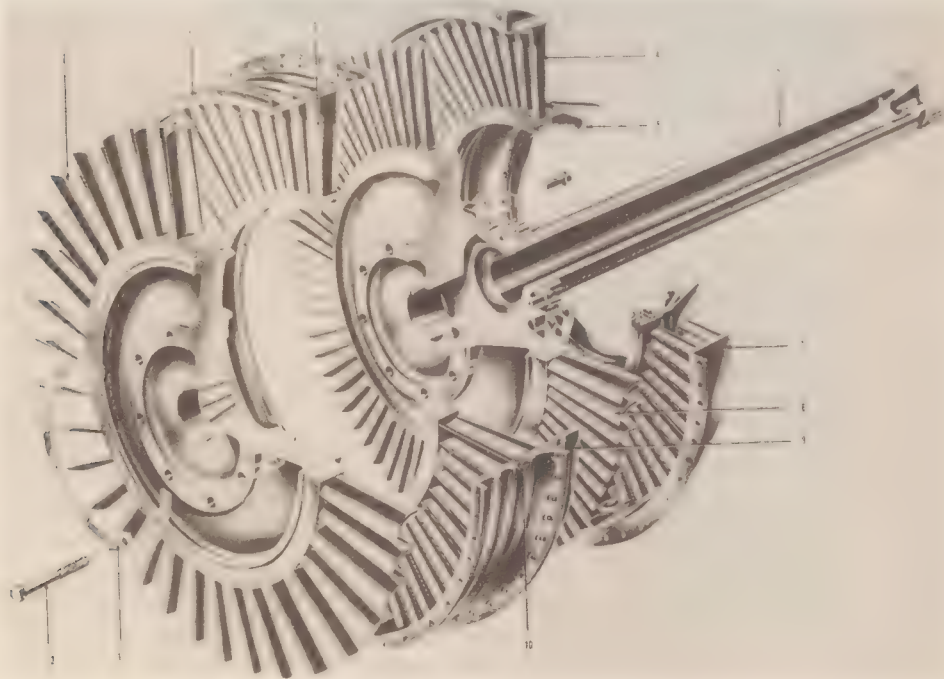


Fig. 13. The turbine assembly of the Westinghouse J34 turbojet engine.

JET AIRCRAFT SIMPLIFIED

Turbine Assembly

Fig. 13 shows the turbine assembly, including the (1) second stage disc; (2) turbine housing; (3) second stage turbine nozzle; (4) first stage turbine nozzle; (5) support; (6) turbine shaft; (7) outer support; (8) first stage disc; (9) spacer ring; (10) retaining bolt; (11) tabring; and (12) disc bolt.

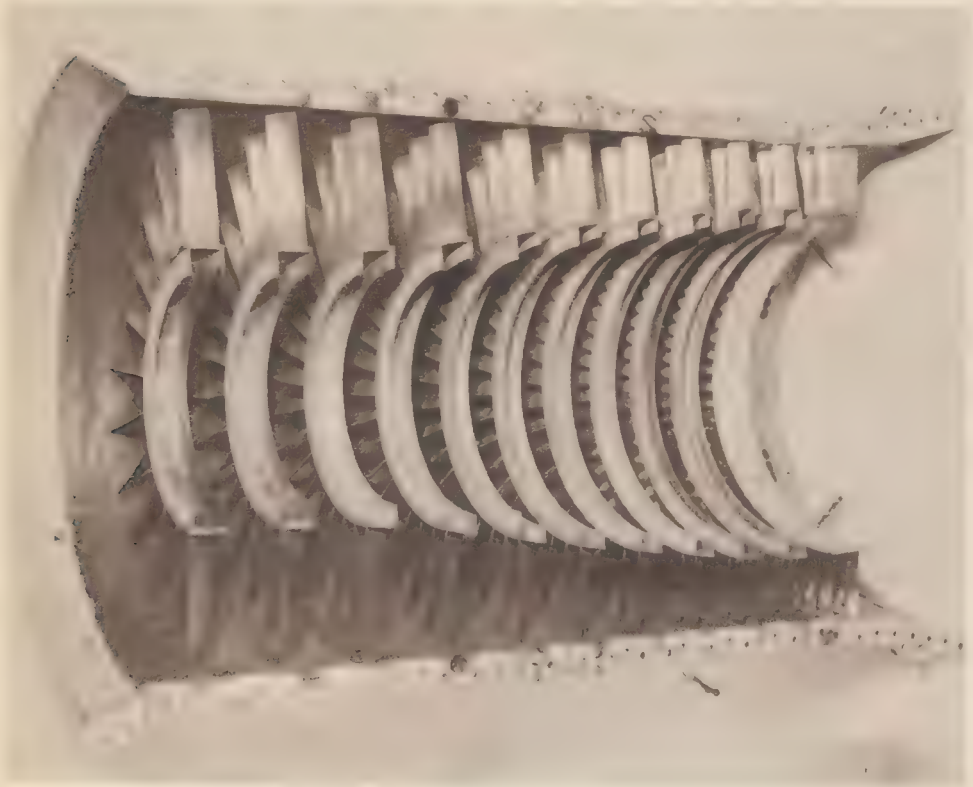


Fig. 14. The compressor vane assembly of the Westinghouse J34 turbojet.

Axial Flow Compressor

Fig. 14 shows the compressor vane assembly and Fig. 15 illustrates the compressor spindle. In the J34 engine, the compressor consists of 11 stages, including a set of stationary inlet guide vanes and two stages of straightening vanes at the outlet end. The compressor spindle includes a ten-stage rotor, machined from a single aluminum forging, and a single steel disk for the eleventh stage, which is bolted to the aluminum rotor. The eleventh stage is made of steel because of the higher temperatures encountered at that stage. The discs of each succeeding stage are larger as the blades become shorter. Thus, the incoming air is compressed by being "squeezed" into a smaller and smaller space.

The axial flow compressor is used in the J34 engine because it presents a reduced frontal area and a relatively high efficiency.

TYPICAL TURBOJETS IN PRODUCTION

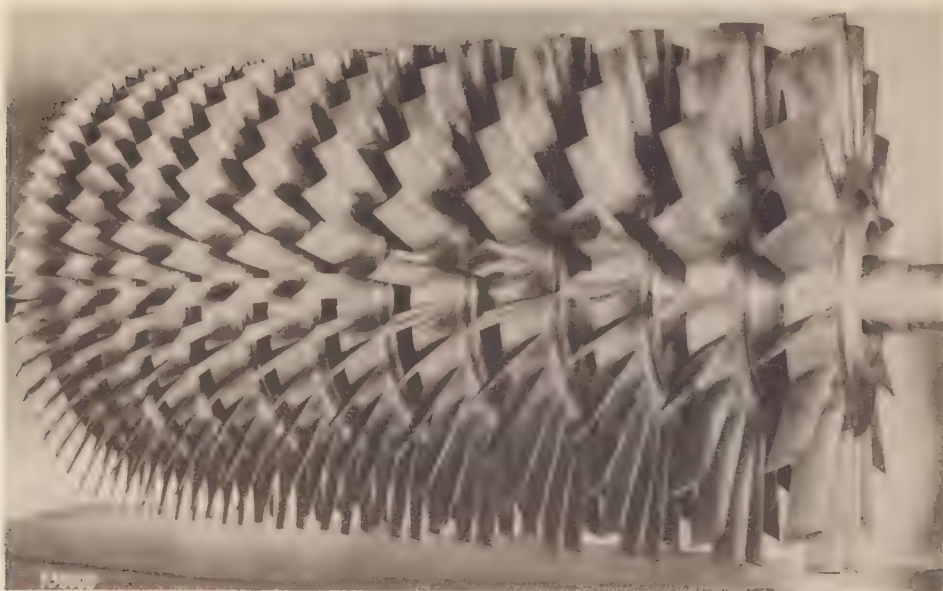


Fig. 15. The compressor spindle of the Westinghouse J34 turbojet.

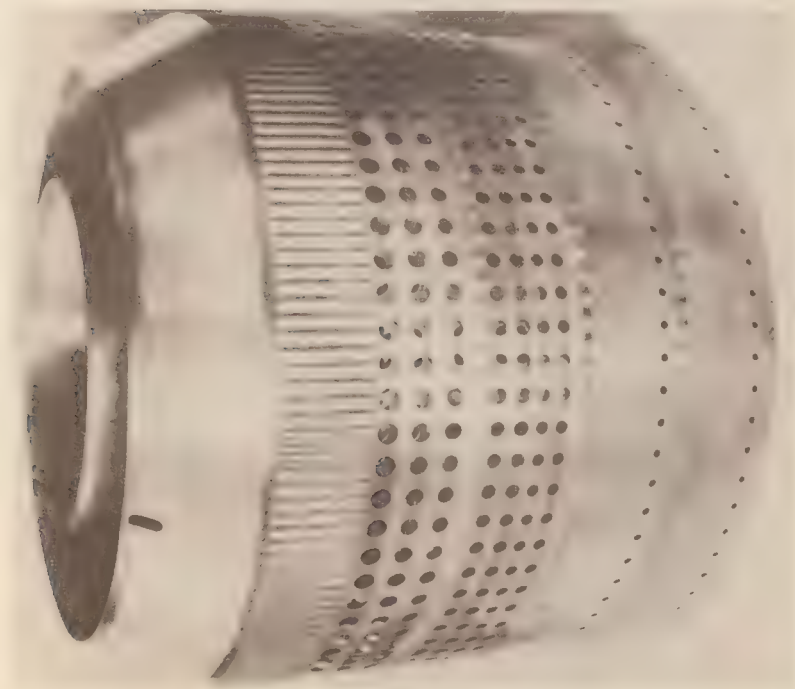


Fig. 16. A side view of the combustion changer of the J34 turbojet.

JET AIRCRAFT SIMPLIFIED

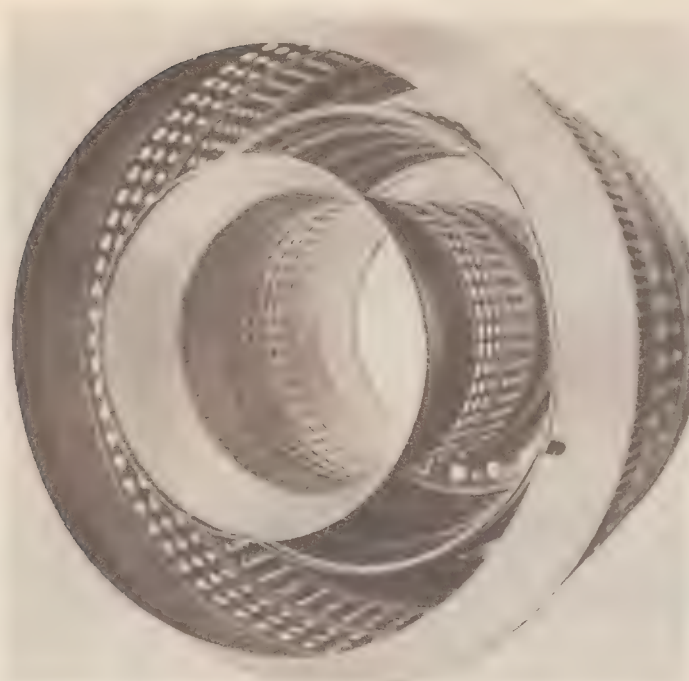


Fig. 17. An end view of the combustion chamber of the J34 turbojet.

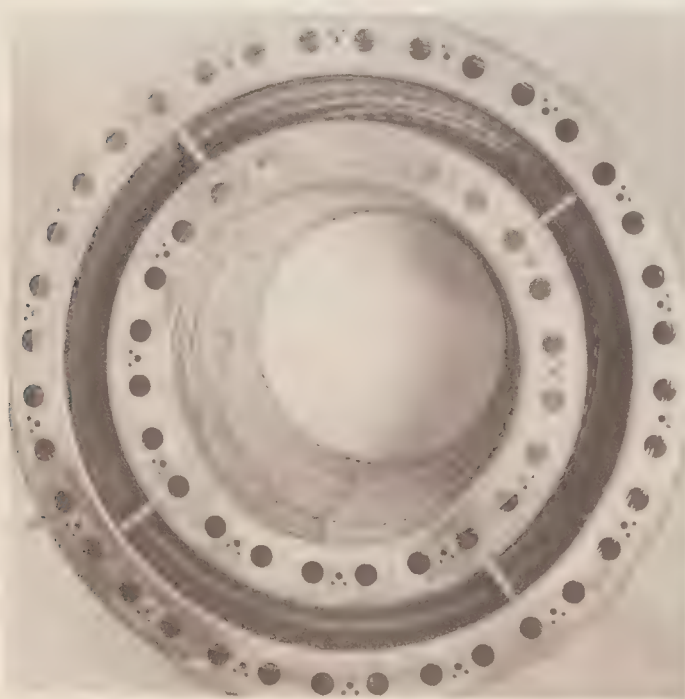


Fig. 18. A view of the other end of the J34 combustion chamber.

TYPICAL TURBOJETS IN PRODUCTION

Annular-Type Combustion Chamber

Fig. 16 is a side view of the combustion chamber. Fig. 17 is an end view of the combustion chamber and Fig. 18 is a view from the other end.

Of the two general types of combustion chambers, the "can" type and the annular type, the annular chamber is used in certain engines, such as the J34, for several reasons. The most important considerations are size and efficiency. Since the compressor provides a small frontal area and a straight-through path for the air, those who prefer this type believe that the combustion chamber should do the same thing.

Turbine Operation

Mechanical power for driving the compressor rotor and the engine-driven accessories is supplied by the two-stage turbine previously mentioned. Each stage of the turbine consists of a turbine nozzle assembly, followed by a rotating-blade assembly.

The hot gases of the combustion chamber flow through the two stages of the turbine, where they give up part of their energy. The exhaust gases from the turbine pass through the exhaust collector and nozzle and are gradually converted into a solid jet at the optimum velocity to produce maximum thrust for the propulsion of the aircraft.

J34 Systems

The J34 has a hydro-mechanical type control system, with automatic acceleration and starting controls. The fuel system is of the single fuel manifold type. There is a dry-sump lubrication system. There is an electric starter, and a shielded low-tension ignition system with one ignition unit, two flame igniters and two transformers.

The J34 is 120 inches long, it has a diameter of 24 inches, the frontal area is 3.1 square feet, and the weight is 1,230 pounds. The dry static thrust at take-off, without an afterburner, is more than 3,400 pounds in the case of the J34-WE-36 (24C-4E) model, and less for earlier versions.

The J34 with an afterburner is 200 inches long and weighs 1,450 pounds. The static dry thrust for take-off is more than 4,200 pounds. The thrust varies with the length of the afterburner, hence versions with a shorter or longer afterburner will vary in thrust.

Turbojet Pressure, Temperature and Velocity

Fig. 19 is a representation of a typical Westinghouse turbojet engine without an afterburner. Fig. 20 is a representation of a typical Westinghouse turbojet engine with an afterburner and a variable-area exhaust nozzle. These two diagrams show the rise and fall of pressure, temperature and velocity from the time that air enters the engine until it leaves.

JET AIRCRAFT SIMPLIFIED

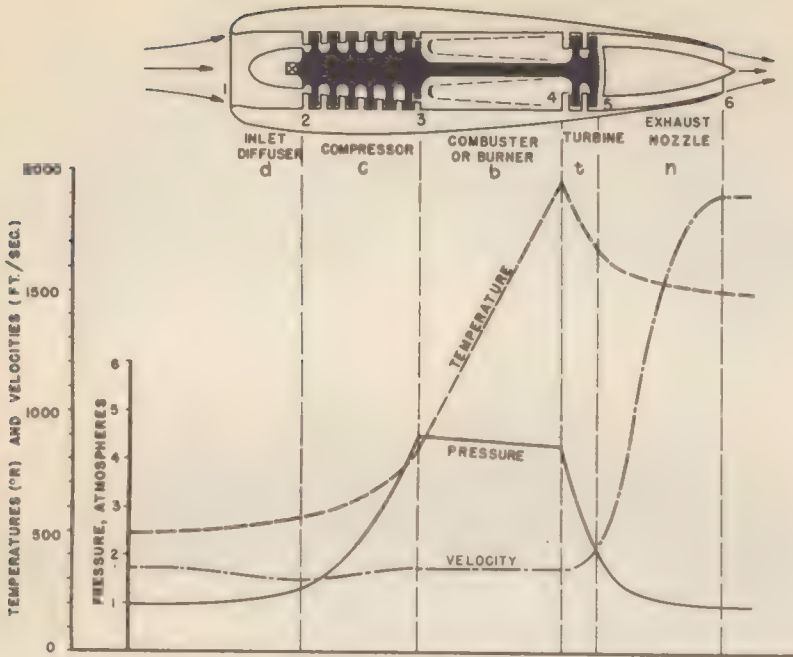


Fig. 19. A representation of a typical Westinghouse jet engine *without an afterburner*, showing the rise and fall of pressure, temperature and velocity.

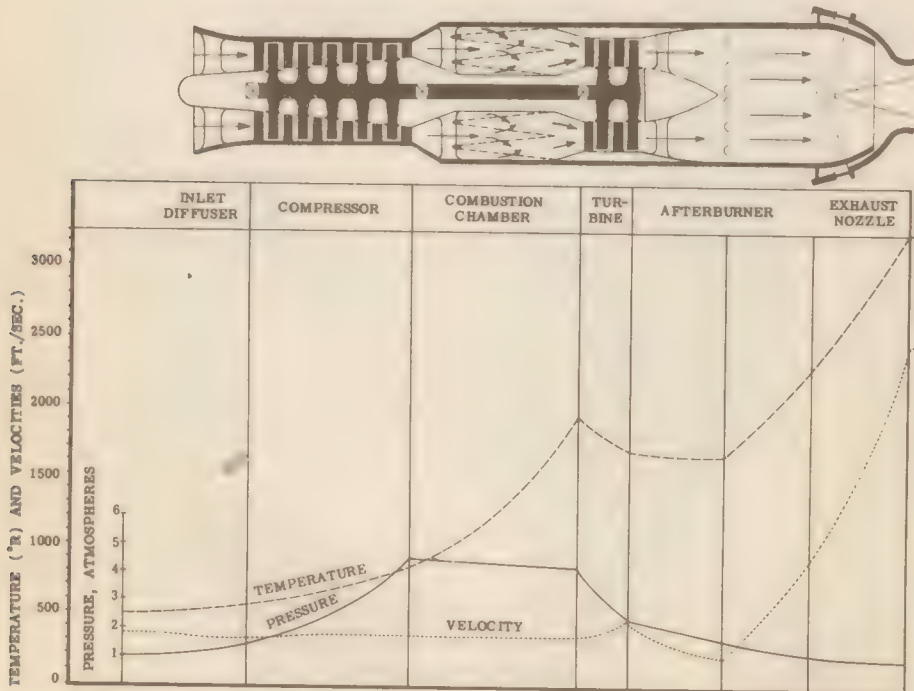


Fig. 20. A representation of a typical Westinghouse turbojet engine *with an afterburner* and a variable-area exhaust nozzle, showing the variations of temperature, pressure and velocity.

TYPICAL TURBOJETS IN PRODUCTION

WESTINGHOUSE J40 TURBOJET ENGINE

The Westinghouse J40 turbojet engine, illustrated in Fig. 21, has a ten-stage axial compressor, one annual combustion chamber, and a two-stage turbine. It develops more than 25,000 horsepower at flight speeds. Comparing it with the engines of the B-29 Superfortress of World War II, a single J40 is two and one-half times as powerful as the combined *four* engines of the B-29, although the weight of the J40 is only about 3,500 pounds for the model with the afterburner, less than the weight of *one* of the B-29 engines with its propeller.

The J40 is twenty-five feet long (with afterburner) and forty inches in diameter. It produces more thrust per square foot of frontal area than any contemporary or previous turbojet engine. Like other Westinghouse jet engines, it is of the axial-flow or straight-through type.

As delivered to airplane manufacturers, for production aircraft, the J40 was the first engine to provide constant speed drives for aircraft accessories as an integral part of the engine, thus providing substantial savings in aircraft weight and space.

The tremendous power of the J40 is partly developed through the use of the afterburner which reheats the exhaust gases after they leave the turbine and before they emerge as a jet stream.

Substantial amounts of two of the most critical metals, columbium and cobalt, were eliminated in the design of the J40. It is believed that even greater savings of these and other scarce materials can be accomplished in newer versions of the engine.

A new low-cost fuel especially developed for use in high-flying jet aircraft, designated as JP-4, was used throughout the qualification tests of the J40.

The J40 was designed by Westinghouse in co-operation with the U. S. Navy Bureau of Aeronautics. Two Navy fighter airplanes powered by the J40 are the McConnell F3H "Demon" and the Douglas F4D "Skyray". Even more powerful versions of the J40 are being developed for these and other aircraft.

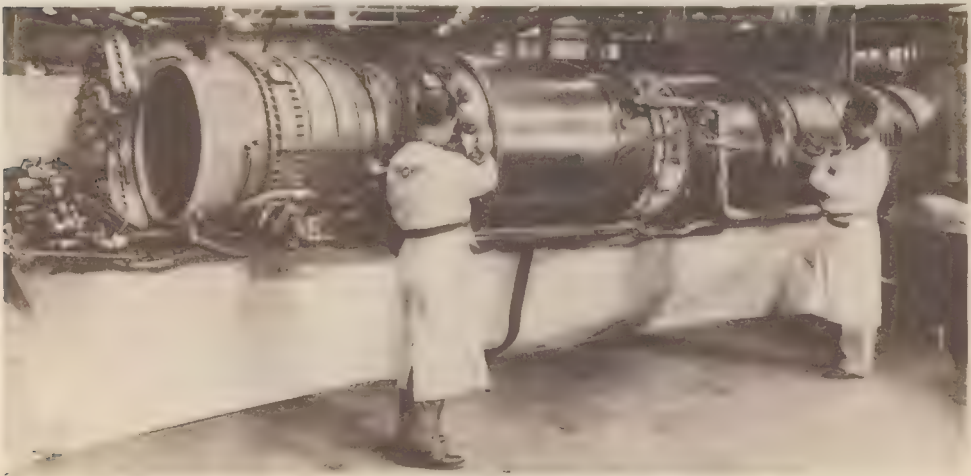


Fig. 21. Mechanics adjusting a Westinghouse J40 turbojet engine.

JET AIRCRAFT SIMPLIFIED

TURBOJET ENGINE MADE BY WRIGHT AERONAUTICAL

WRIGHT J65 "SAPPHIRE" TURBOJET

Fig. 22 is a photograph of a Wright J65 "Sapphire" turbojet engine made by the Wright Aeronautical Division of the Curtiss-Wright Corporation, Wood-Ridge, New Jersey. It has a 13-stage axial compressor, a 2-stage turbine, and one annular combustion chamber. The exhaustor is of the fixed area type. There is a single fuel manifold fuel system. There is a dry sump lubrication system. The dry, static thrust at take-off is 7,200 pounds. The diameter is 37.5 inches, the length is 146 inches, the frontal area is 7.7 square feet and the weight is 2,600 pounds.

The J65-W-1 is the U. S. Air Force version. J65-W-2 is a Navy model, and there are other versions. All forms of the J65 are manufactured under license from Armstrong Siddeley Motors, Ltd., of Great Britain. One version, designated J65-B-3, has been built by the Buick Motor Division of the General Motors Corporation.

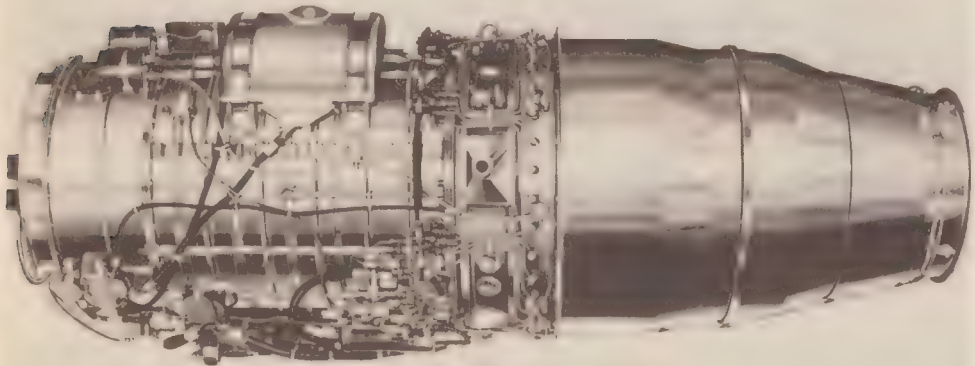


Fig. 22. Wright J65 "Sapphire" turbojet engine.

CHAPTER VIII

AIRPLANES POWERED BY TURBOJET ENGINES

BELL X-5

The Bell X-5, made by the Bell Aircraft Corporation, Buffalo, New York, is the first airplane in which the degree of wing sweepback may be varied in flight.

It is a single-seat research monoplane used to study the aerodynamic effects of sweepback change and was designed to operate in the transonic flight range.

The requirement for the X-5 airplane evolved soon after World War II with the first general use of sweptback wings. Preliminary studies indicated that drag could be lessened as the sweepback angle of the wings increased. However, a low sweepback angle was most desirable for takeoff and landing.

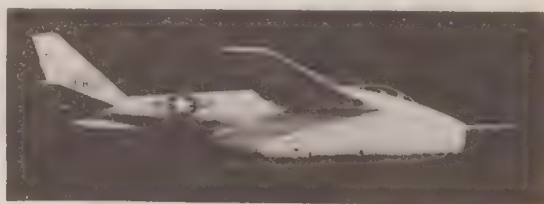
A sweepback angle range of from 20 to 60 degrees was decided by the NACA, the Air Force and Bell, and the company contracted to build two ships. Preliminary design was begun in 1948.

The X-5 is powered by one Allison J-35-A-17 turbojet engine mounted beneath approximately the second and third quarters of the ship's fuselage. The air inlet extends in direct line beneath the pilot's cockpit from the nose of the ship. The short tailpipe exhausts under the fuselage.

Fig. 1 shows the X-5 in three different views as its wings are being changed from their normal flight position to their fully swept back position. The fairing for each wing root is designed so that the leading edge of each wing root offers a smooth surface for any angle of sweepback. The wings have full-span leading-edge slats. A special mechanism compensates for changes of the center of gravity caused by variations of wing sweepback.



The X-5 begins to sweep its wings.



Wings are moved back 50 per cent.



Wings now in fully swept position.

Fig. 1. Bell X-5 wings being swept back.

JET AIRCRAFT SIMPLIFIED

The three wheels of the tricycle-type landing gear retract into the fuselage. The dive brakes resemble doors which are opened until they are almost perpendicular to the fuselage. They are forward of the cockpit, in the sides of the fuselage, and operate hydraulically.

The cockpit, which is ahead of the leading edge of the wings, is air-conditioned and pressurized. The sliding canopy and the seat can be jettisoned. A cordite-cartridge type of ejection seat is used.

Dimensions: Height, (over fin), 12 feet; length, 32 feet, 4 inches; span, 32 feet, 9 inches, in normal position; weight loaded, about 5 tons.

BOEING B-47 STRATOJET BOMBER

The Boeing B-47 Stratojet Bomber is a six-jet engine swept-wing bomber built in quantity for the U. S. Air Force by Boeing Airplane Co., of Seattle, Washington, at its Wichita, Kansas plant. The Boeing-designed B-47 also is produced by Douglas Aircraft Co., Inc., at Tulsa, Oklahoma, and by Lockheed Aircraft Corporation at Marietta, Georgia. In size it is generally similar to the Boeing B-29 and the B-50 Superfortresses.

The U.S. Air Force describes this as a medium bomber "in the 600-mile-an-hour class". It was the first large jet-propelled airplane built with sweptback wings and sweptback tail surfaces. The first flight of the original XB-47 was made on December 17, 1947. On a transcontinental flight, it averaged 607.8 miles per hour. On this flight, it was equipped with six General Electric J-35 turbojet engines of about 4,000 pounds thrust each, making a total thrust of about 24,000 pounds. Production models have six General Electric J-47 turbojet engines, and although their size and weight is roughly similar to that of the J-35, each engine gives more than 5,800 pounds of thrust, making a total thrust of about 34,800 pounds. Emergency take-off thrust can be obtained from eighteen individual Jato solid-fuel rockets which give a total thrust of about 18,000 pounds.

The range is more than 3,000 miles; the ceiling is over 40,000 feet; the bomb load is more than 10 tons; the gross weight is about 185,000 pounds for takeoff; the length is 106 feet, 8 inches; the span is 116 feet; and the height is 27 feet, 11 inches. The sweepback is 35 degrees. It carries two .50-caliber machine guns in the tail turret. A crew of three works in compartments which are air-conditioned and pressurized. The bombardier rides in the nose. The pilot and co-pilot are seated in tandem under a bubble-type canopy. All three crew members have catapult-type ejection seats.

A retractable tandem-type landing gear has two main twin-wheel units, one forward of the bomb-bay and one aft of the bomb-bay, which retract forward into the fuselage. On each side of the airplane, there is a small outrigger wheel unit near the wing tip which retracts into the inboard engine nacelle. These outrigger wheels provide lateral stability on the ground.

Two XB-47 airplanes were made, both fitted originally with the G.E. J-35. In 1949, one was refitted with a J-47. The B-47-A and the B-47B both had G.E. J-47 engines. The B-47E followed the B-47B in production and is fitted with six General Electric J-47 engines.

Fig. 2 shows the airplane in flight, and Fig. 3 shows the B-47 in flight as it appears to an observer above it.



Fig. 2. Boeing B-47E Stratojet Bomber.

JET AIRCRAFT SIMPLIFIED



Fig. 3. Boeing B-47E Stratojet as it appears from above.

BOEING B-52 STRATOFORTRESS

The B-52 Stratofortress is an eight-jet, swept-wing, long-range heavy bomber which was first test flown on April 15, 1952. Although the B-52 is completely different from the B-47 insofar as both mission and design are concerned, outwardly the two are similar in appearance. Both have a 35-degree angle of wing sweepback, tandem landing gear, and typical Boeing-designed jet engine pods. However, the B-52 is much larger than the B-47 and gives the viewer an impression of massiveness rather than the sleekness which characterizes the Stratojet. One of the most prominent features of the B-52 is its vertical tail fin which rises 48 feet above the ground. A conventionally mounted tail plane on the B-52 is much less rakish than the step-mounted, swept-back B-47 horizontal stabilizer.

Internally, the B-52 is entirely new, both structurally and in its systems. The wing is entirely new and the control surfaces are unconventional.

The wingspan is 185 feet; the sweepback is 35 degrees; the length is 153 feet; and the height of the tail is 48 feet. The weight is more than 300,000 pounds. The airplane is powered by eight Pratt & Whitney J-57 turbojet engines. The landing gear has quadruple main wheels in tandem arrangement with single outrigger wingtip, "protection" wheels, which normally do not contact the earth, but do provide lateral stability when the airplane is on the ground. The speed, service ceiling, bomb load, range, and crew are classified facts which are not released.

AIRPLANES POWERED BY TURBOJET ENGINES



Fig. 4. Boeing B-52 Stratofortress during landing roll.

Fig. 4 shows the B-52 during the landing roll with its ribbon parachute slowing it down. Fig. 5 shows the airplane in flight.



Fig. 5. Boeing B-52 Stratofortress in flight.

JET AIRCRAFT SIMPLIFIED

CHANCE VOUGHT F7U CUTLASS

The Chance Vought Cutlass, which is shown in Fig. 6, is known to the Navy as F7U and is manufactured by the Chance Vought Aircraft Division of United Aircraft Corporation, Dallas, Texas. The newest version, the F7U-3, is a twin-jet, swept-back wing, single-seat, tailless, aircraft carrier-based fighter designed to give the U.S. Navy a fast shipboard fighter offering superior performance, a greater rate of climb, greater range, and more firepower. It has been described as surpassing any other airplane flown by the armed forces of the United States or any enemy nation.



Fig. 6. Chance Vought F7U Cutlass.

The F7U-3 has a dual hydraulic power control system. Each hydraulic system is completely independent. Neither can fail because of a breakdown of any component of the other system.

Instead of an airplane tail section, the Cutlass has two vertical stabilizers and rudders at the trailing edge of the wing, "Elevons", which are combined ailerons and elevators, provide longitudinal and lateral control. Leading edge wing slats replace the conventional landing flaps to attain the low stalling speed essential for carrier-based aircraft.

Two Westinghouse J-34-WE-32 turbojets with afterburners powered the F7U-1 from which the F7U-3 was developed. An attack version of the F7U-3 is called the A2U-1 by the Navy.

In the design of the F7U-3, emphasis was placed on reducing the time required for inspection, maintenance and repair on a carrier. The number of access doors and panels on the F7U-1 was tripled in the F7U-3. The cockpit was improved so that four or five maintenance men can work on the cockpit from the outside while another worker is inside. All consoles are removable as units. The electronics sections and gun sections are easily accessible.

In the F7U-1, the engine was removed through engine access doors in the bottom of the fuselage, but in the F7U-3, the engine is removed aft. This saves time and provides better access to the afterburners. Maintenance and servicing

AIRPLANES POWERED BY TURBOJET ENGINES

have been simplified by running all electrical lines on the right side and all hydraulic lines, with a few exceptions, on the left side. The two sets of speed brakes on the F7U-1 were replaced by a single set on the F7U-3. Since the F7U-3 is heavier than its predecessor, it has a heavier nose landing gear with dual wheels. The arresting hook installation was simplified.

CONVAIR YB-60

The Convair YB-60, manufactured by Consolidated Vultee Aircraft Corporation, San Diego, California, is shown in Fig. 7. It is equipped with eight Pratt & Whitney J-57 turbojet engines. This swept-wing bomber was first flown on April 18, 1952. It is nine feet longer and three feet three inches higher than the Convair B-36. Although the wingspan of the B-36 is 230 feet, the shorter wingspan of the YB-60 is caused by the sweep of the YB-60's wings which reduce the span from tip to tip. The needle-nose appearance of the airplane is caused by a slender boom used for test purposes only and discarded in production models.



Fig. 7. Convair YB-60 eight-jet bomber in flight.

CONVAIR B-36D LONG-RANGE BOMBER

Fig. 8 is a three-view outline drawing of the Convair B-36D Long Range Bomber. This is a high-wing, all-metal, land-based, closed monoplane with a design range of 10,000 miles carrying a 10,000-pound bomb load approximately halfway. The maximum bomb load for lesser ranges is 42 tons (84,000 pounds).

The Convair RB-36 reconnaissance version carries special photographic equipment instead of bombs. Both types are built for the U.S. Air Force by Consolidated Vultee Aircraft Corporation (Convair) at their Fort Worth, Texas, plant.

JET AIRCRAFT SIMPLIFIED

The wingspan is 230 feet, length 162 feet, height (tail tip) 46 ft. 9 in., gross weight (maximum) 358,000 lbs., maximum speed over 435 miles per hour, service ceiling over 45,000 ft., design range 10,000 miles, design bomb load 10,000 lbs., maximum bomb load 84,000 lbs., crew 15 (including 4 relief members).

The landing gear is of the tricycle type with a steerable dual nose and four-wheel truck-type main gears.

The power plant consists of six Pratt & Whitney Wasp Major piston engines of 3,800 horsepower each, and four General Electric J-47 turbojet engines, each having a thrust of more than 5,000 lbs. The airplane has six Curtiss electric, 3-bladed propellers, each having a diameter of 19 feet and reversible pitch.

These specifications apply to the "F" and "H" series of B-36 and RB-36 aircraft except for the bomb load in the case of the RB-36. The "D" series airplanes have the same specifications except that piston engines develop only 3,500-horsepower each. All B-36 and RB-36 airplanes preceding the "F" series are equipped with four J-47 turbojets in addition to six 3,500-horsepower piston engines.

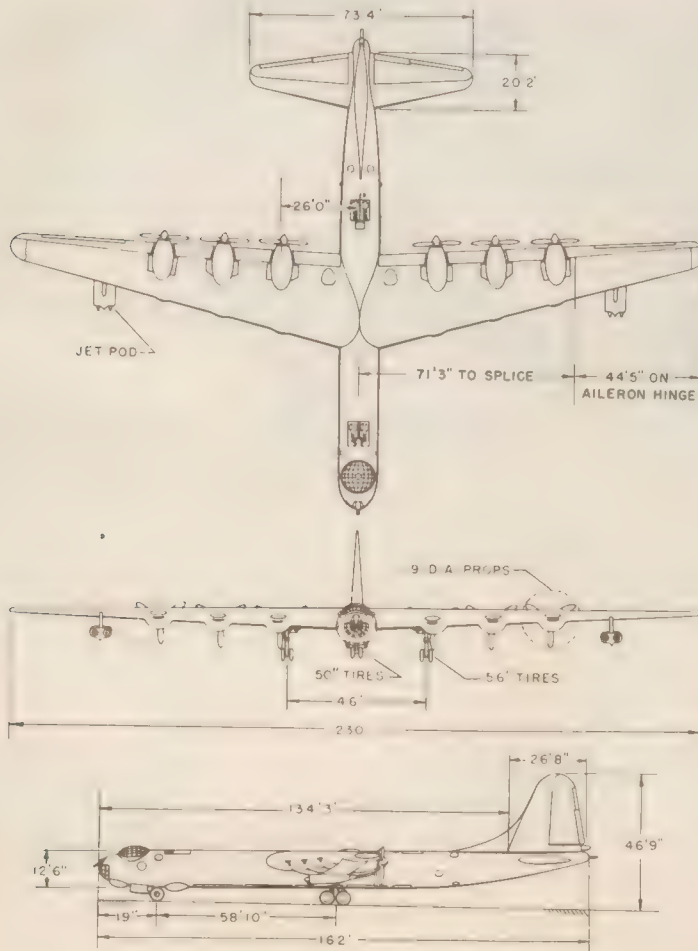


Fig. 8. Three-view drawing of the Convair B-36D Long-Range Bomber.

AIRPLANES POWERED BY TURBOJET ENGINES

Externally, the RB-36 reconnaissance airplane closely resembles the B-36 bomber; but instead of bombs, the RB-36 carries the large cameras and other special equipment needed in long-range high-altitude reconnaissance. In the RB-36 forward bomb bay, for example, are 14 different cameras including one with a 42-inch focal-length lens. This is probably the largest photographic set-up ever designed into one airplane.

The B-36 bomber and the RB-36 reconnaissance airplane have the same defensive armament. They are protected by eight remotely controlled turrets containing a total of sixteen 20-millimeter cannons, thus having more firepower than any other known bomber. All turrets, except those in the nose and tail, are retractable.

The six R4360-53 piston engines drive 19-foot-diameter reversible-pitch propellers, which act as a braking force during the airplane's landing run. These three-bladed, hollow-steel propellers have a built-in thermal anti-icing system for all-weather operation. Leading edges of the B-36's wing and tail are double-skinned to permit the flow of heated air for anti-icing. Heated air also defrosts the pilots' and bombardier's enclosures and the several sighting blisters.

The central portion of the 230-foot wing, which is mounted slightly forward of the midpoint of the fuselage, is seven and one-half feet thick, which is high enough to permit installation of a catwalk so that crew members can climb into the wing for access to the nacelles during flight. Six wing tanks hold more than 21,000 gallons of gasoline and 1,200 gallons of oil.

In order to travel back and forth between the pressurized forward and aft crew compartments, a crew member uses a four-wheel scooter, operating on rails and running through an 85-foot long pressurized tunnel. He lies down on the scooter and pulls himself along by means of an overhead cable.

In spite of its size, this giant bomber is controlled with ease by the pilot. The huge control surfaces, almost as large in area as the entire wing of the Consolidated Vultee B-24 Liberator bomber flown in World War II (known to the Navy as the PB4Y-1 and PB4Y-2), are operated without any power boost by spring tabs attached to the trailing edge of the control surfaces. The pilot operates only these tabs, which in turn move the control surfaces by aerodynamic forces.

An experimental transport version of the B-36, designated XC-99, was produced to fly heavy loads of high-priority cargo between various depots of the Air Materiel Command of the U.S. Air Force. It can haul 400 troops or 100,000 pounds of cargo.

THE CONVAIR XF-92 A

The XF-92A, originally Convair Model 7002, is a single-place midwing monoplane with 60-degree sweepback at leading edges of the delta wing and delta vertical fin. "Elevons" form part of the wing trailing edges, replacing conventional ailerons and elevators. The control system has a built-in artificial feel, 100-percent hydraulic boost with no feedback. This airplane was designated as a research interceptor and not provided with armament. It has been built by the San Diego Division, Consolidated Vultee Aircraft Corporation, for the United States Air Force. The first flight was on September 18, 1948.

This radically designed aircraft is being used to explore and test the stability and control characteristics of the "delta wing". This type of wing differs from



Fig. 9. One of the Air Force's newest delta wing airplanes—Convair XF-92A.

AIRPLANES POWERED BY TURBOJET ENGINES

the conventional wing in that it has a much larger degree of sweepback, 60 degrees, as compared to 35 degrees, which is the maximum used previously in United States aircraft. The wing is triangular shaped and incorporates elevons in the trailing edge for aileron and elevator action, thus eliminating the need for a tail section. A vertical stabilizer and rudder are provided to give added directional control and stability.

Experimentation and evaluation of the aerodynamic characteristics of the delta wing have been carried on in wind tunnels for several years and these tests have indicated that the wing has low drag characteristics and satisfactory control in transonic and supersonic speed ranges.

The wingspan is 31 feet 3 inches, the length is 42 feet 5 inches, the height (at tip of vertical fin) is 17 feet 8 inches, the weight (takeoff gross) is 15,000 pounds, the speed is high subsonic, the service ceiling is over 45,000 feet, the landing gear is of the tricycle type with single-wheel main gears. The powerplant is one Allison J-33A-29 turbojet which delivers 5,200 pounds dry thrust with an afterburner.

Fig. 9 shows the XF-92A in a flight view taken from the tail gunner's position in a B-35 bomber high above the Mojave Desert in California. The parallel lines on the wing at the left are rows of wool tufts which show the direction of the air flow. Motion picture cameras installed in the airplane's vertical fin provide film records of each flight. On the completion of tests by the U.S. Air Force, this airplane was assigned to the National Advisory Committee for Aeronautics for flight tests to substantiate ultra high speed air-flow theories. Fig. 10 is a three-view outline drawing of the XF-92A.

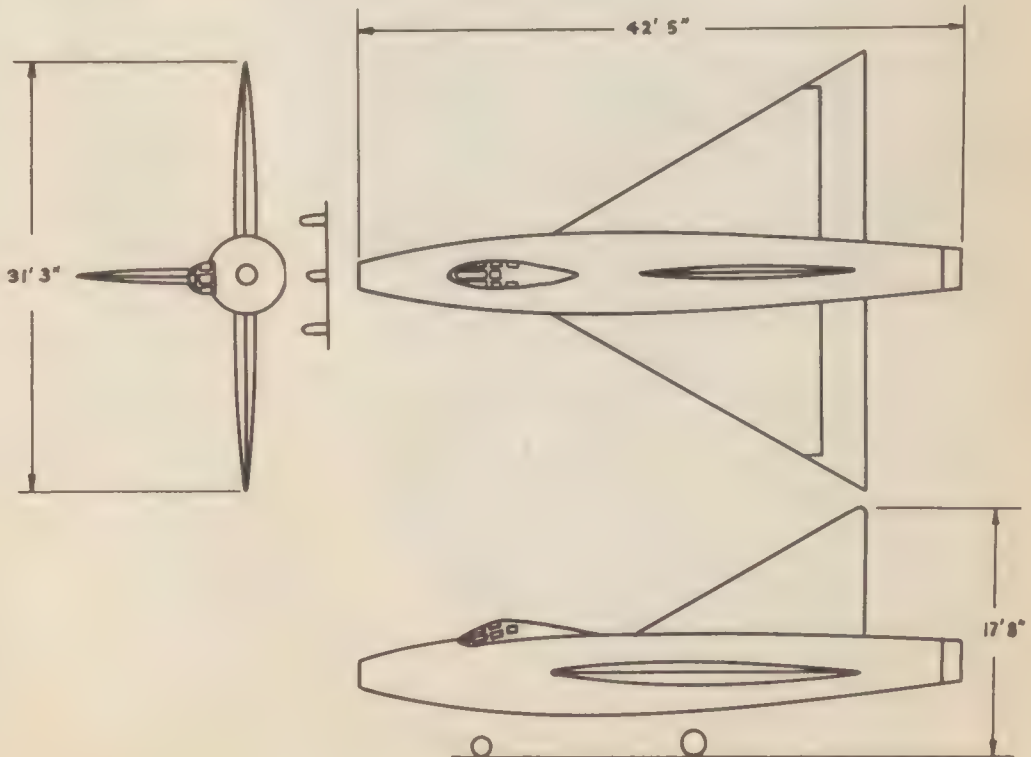


Fig. 10. Three-view drawing of the Convair XF-92A.



Fig. 11. Launching of the Convair XP-2Y Sea Dart.

AIRPLANES POWERED BY TURBOJET ENGINES

THE CONVAIR XF2Y-1 SEA-DART

The Convair XF2Y-1 Sea-Dart, a delta-wing, supersonic, fighter-type seaplane with a successful blending of the high-speed land-based airplane's performance with the water-based airplane's inherent mobility and versatility is shown in Fig. 11 as it was launched on San Diego Bay to start pre-trial runs. It has no horizontal tail, but is equipped with a triangle-shaped vertical fin and rudder. "Elevons" on the wing trailing edge replace conventional ailerons and elevators for control action.

The XF2Y-1 has hydro skids to provide better rough water landing and take-off characteristics. This is the first application of the hydro ski to a combat-type aircraft in the United States and probably the first in the world. In the air, the Sea-Dart retracts the skis, and extends them again when coming in to land.

The Sea-Dart is powered by two Westinghouse J-34 turbojet engines carried high on each side of the fuselage, separated by the triangle-shaped vertical stabilizer (fin). Both engines have afterburners.

CONVAIR F-102 DELTA-WING INTERCEPTOR

Fig. 12 is an artist's conception of workmen removing the tarpaulin from the Convair F-102 delta-wing interceptor which is being built at the San Diego plant of Consolidated Vultee Aircraft Corporation for the U.S. Air Force. The new airplane is designed for very high speeds in the stratosphere and includes improvements in armament and electronic devices. Like all true delta airplanes, the F-102 has no horizontal tail, but is equipped with a vertical fin-rudder and has "elevons" on the wing trailing edge instead of aileron and elevator controls. This is a super secret Air Force project, and details of design and performance are not releasable.



Fig. 12. Convair's newest super secret delta-wing interceptor the F-102.

JET AIRCRAFT SIMPLIFIED

DOUGLAS D-558-1 SKYSTREAK

The Douglas D-558-1 Skystreak, illustrated in Fig. 13 by a three-view drawing and by a photograph in Fig. 14, was a straight wing experimental airplane with wing tanks (shown in dotted lines at the tips of the wings) which could be detached and thrown off after use. The line drawn through the cockpit indicates the point at which the pilot detached the nose section to bail out. This airplane was powered with one Allison J-35 turbojet located in the fuselage over the wing and occupying the major portion of the space within the fuselage. The engine was supplied with air entering the nose of the fuselage and flowing around the pilot's cockpit in two separate ducts. The engine exhaust was at the extreme aft end of the fuselage. The engine delivered about 4,000 pounds of thrust. Three Skystreaks were built by Douglas for the U. S. Navy and the National Advisory Committee for Aeronautics.

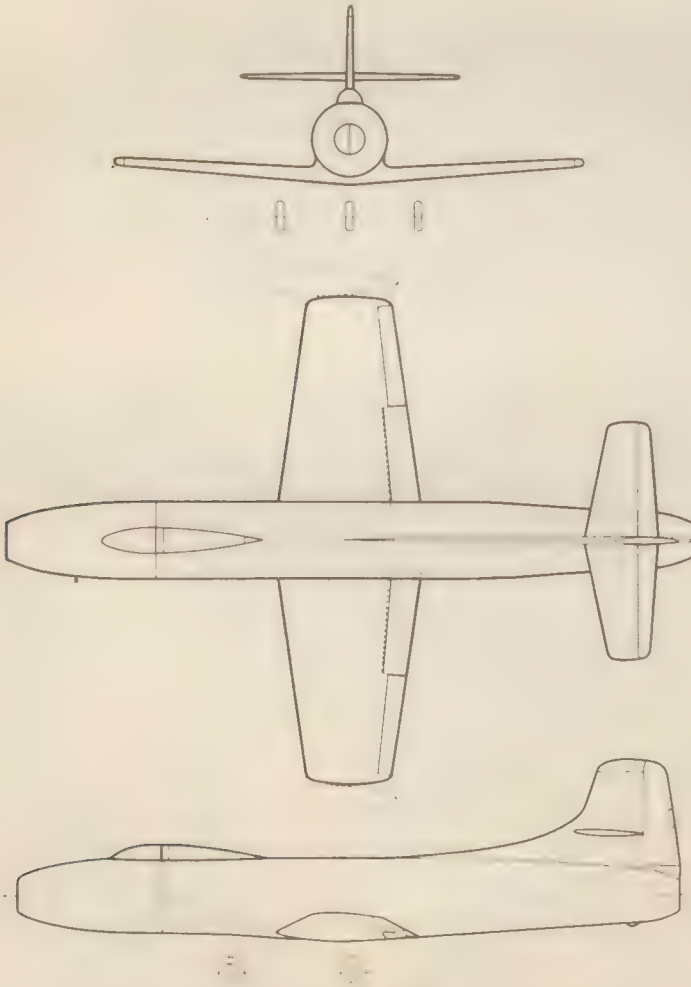


Fig. 13. A three-view drawing of the Douglas D-558-1 Skystreak.

AIRPLANES POWERED BY TURBOJET ENGINES



Fig. 14. Douglas D-558-1 Skystreak in flight.

DOUGLAS D-558-2 SKYROCKET

Within a short time after development of the Douglas D-558-1 Skystreak began, it was decided that a second design, the Douglas D-558-2 Skyrocket, should be undertaken to investigate the effect of swept-back wings and to study supersonic flight. A silhouette drawing of this airplane is shown in Fig. 15. The needle-nosed thin shape gives it the appearance of a flying bomb. It has two power plants, a Westinghouse J-34 turbojet (also known as a 24C) mounted amidships, with a flush exit under the fuselage and flush inlets forward. A Reaction Motors bi-fuel rocket engine is in the tail and provides about 6,000 pounds thrust. Since this is an experimental airplane, the make, model and type of engines may be varied from time to time. Fig. 16 is a photograph of the airplane in flight.

In August, 1951, a Navy P2B-15 (B-29) airplane carried a Skyrocket to an altitude of 35,000 feet, where the Skyrocket, with its jet engine removed and its rocket-fuel capacity increased, reached the highest altitude and greatest speed ever officially recorded for a piloted aircraft. The rocket engine used for the flight was one of the liquid propellant series, designed and built by Reaction Motors, Inc., and producing a thrust of 6,000 pounds. The speed was 1,238 miles per hour and the altitude was 79,494 feet. In the summer of 1953 a maximum altitude of 83,235 feet was attained.

Three Skyrockets were made and eventually all were assigned to the National Advisory Committee for Aeronautics for research purposes.

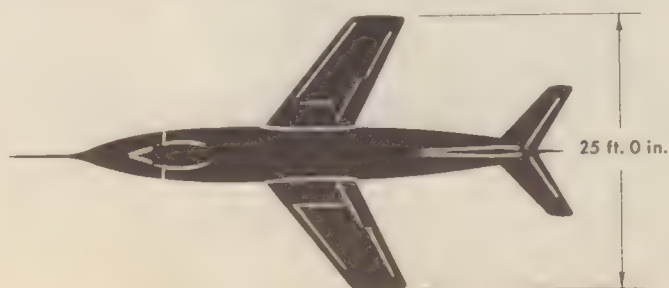


Fig. 15. Silhouette of Douglas D-558-2 Skyrocket.



Fig. 16. Douglas D-558-2 Skyrocket flying under rocket power only.



Fig. 17. Cutaway drawing of Douglas F3D Skynight.

JET AIRCRAFT SIMPLIFIED

DOUGLAS F3D SKYKNIGHT

The Douglas F3D Skyknight, illustrated in the cutaway drawing Fig. 17, is a Navy two-seat, carrier-based, all-weather night-fighter, powered by two Westinghouse J-34 turbojet engines delivering 3,600 pounds of static thrust each, mounted on opposite lower sides of the fuselage. Either one of the engines can keep the Skyknight in the air. Body-type brakes are mounted in the fuselage. These air brakes reduce speed very fast.

The first production version, called the F3D-1, flew on February 13, 1950. The second production version, known as the F3D-2, was first flown on February 14, 1951. This was primarily intended for the U. S. Marine Corps. Wing spoilers were added to improve lateral control. A thicker bullet-proof windscreen and a new type General Electric G-3 autopilot were installed.

The crew consists of two men. The high efficiency of the design makes it possible to fly the F3D at advanced speeds and exceptionally long distances, making it adaptable as an attack fighter, long-range patrol or reconnaissance airplane, or as a long-range fighter escort.

A novel method of escaping from the airplane in case of an emergency is used. The bail-out chute or slide opens under the fuselage to permit the two-man crew to leave the airplane safely while traveling at high speed. Similar in principle to the slide fire-escape chute used in some school buildings, it minimizes the danger to the crew of striking tail surfaces. At lower speeds, bail-out is made by the normal cockpit method.



Fig. 18. Douglas XF4D Skyray—"delta" wing.

AIRPLANES POWERED BY TURBOJET ENGINES

DOUGLAS XF4D SKYRAY

Fig. 18 shows the Douglas XF4D Skyray in flight. This is a single-seat, "delta" wing, tail-less, supersonic monoplane designed for the U. S. Navy as a carrier-based fighter designed specifically as an interceptor capable of catapult take-off from a carrier and rapid climb to the upper atmosphere, where it can intercept enemy aircraft before they can attack fleet or ground installations.

On October 3, 1953, the Skyray was flown at an average speed of 783.4 miles per hour by Lieutenant Commander James B. Verdin of the U.S. Navy, through four all-out passes over a three-kilometer measured course above the Salton Sea in Southern California. The speed of sound when these flights were made was estimated at 792 miles per hour. Two passes were made in each direction to offset wind effects. The altitude was between 100 feet and 200 feet on each pass.

The powerplant is a Westinghouse J-40 turbojet engine with an afterburner.

DOUGLAS A3D ATTACK BOMBER

The Douglas A3D, illustrated in Fig. 19, is a swept-wing, carrier-based Navy attack bomber powered by two Westinghouse J-40 turbojet engines, each suspended in a pod under the wing. It can be used as a high altitude, high-speed attack airplane, or at a low level for mine laying. Also, it can be adapted aboard its carrier for photo reconnaissance.

The airplane was built to perform in the 600 to 700 mile-per-hour speed range, and it can fly at altitudes above 40,000 feet on its combat missions. It has an internal bomb-bay and can carry very large bombs, torpedoes, or other munitions designed for striking actions based on carriers.

The high-wing design of the A3D permits it to easily carry its underwing jet-engine pods. The wing and the tail both fold for compact handling and storage aboard the carrier.

The crew of three are the pilot, pilot-bombardier, and the gunner-navigator. They work in a pressurized cabin and each can operate any position when necessary.

The slide-type escape chute is similar to that on the Navy F3D Skyknight twin-jet fighter.

Speed brakes on the A3D are like those on the Douglas A1D Skyraider attack-bomber. The dive brakes open out from the sides hydraulically to facilitate rapid descent without an excessive build-up in speed.



Fig. 19. Douglas A3D attack bomber.

JET AIRCRAFT SIMPLIFIED



Fig. 20. Grumman F9F Panther.

GRUMMAN F9F PANTHER

The Grumman F9F Panther was originally known as the Grumman G-79 Panther. Originally, the designers planned on four Westinghouse 19XB-2B, Navy J-30, axial-flow turbojet engines, but this idea was abandoned in favor of one turbojet engine mounted in the fuselage.

The F9F-2 Panther was a single-seat, carrier-based, Navy jet fighter whose mission was the destruction of opposing aircraft and ground support. The first flight of this version was November, 1948. In its F9F-2 form, the wingspan was 38 feet, the length 37 feet three inches, the gross weight about 19,000 pounds or more, the range more than 1,200 miles, the maximum speed above 600 miles per hour, and the armament was four 20 mm. guns plus bombs. The pilot constituted the whole crew. The powerplant consisted of one J-42-P-8 Pratt & Whitney turbojet engine, which had a thrust of about 5,000 pounds.

The F9F-3 Panther, illustrated in Fig. 20, was a Navy carrier-based jet fighter which could fly faster than 600 miles per hour. Some of the production models had the Allison J33-A-23 turbojet engine and others had an American-made British Nene turbojet engine. The Allison J33-A-23 was rated at 4,600 pounds thrust but with water and alcohol injection it was rated at 5,400 pounds.

The F9F-4 Panther was equipped with the Allison J-33-A-16 turbojet engine which delivered a thrust of 5,850 pounds.

The F9F-5 Panther is a carrier-based, Navy, single-seat, jet fighter with two removable tip tanks which feed into the main fuel tank, but these tanks are not droppable in flight. A pressurized cabin with temperature control and a Grumman ejection seat are installed. The first flight was in December, 1951.

This F9F-5 version has a wingspan of 38 feet, it is 38 feet 10 inches long, has a maximum gross weight up to 21,245 pounds, has a range of about 1,200 miles, a one-man crew, a maximum speed of more than 600 miles per hour, and four 20 mm. guns, together with bombs and rockets. The powerplant is one Pratt & Whitney J-48-P-6 turbojet engine, which delivers a thrust of about 6,250 pounds.

AIRPLANES POWERED BY TURBOJET ENGINES



Fig. 21. Grumman F9F-6 Cougar.

GRUMMAN F9F-6 COUGAR

The Grumman F9F-6 Cougar, illustrated in Fig. 21, is really a swept-wing development of the F9F Panther and, like the Panther versions, is made by the Grumman Aircraft Engineering Corporation at Bethpage, Long Island, New York.

The Grumman F9F-6 Cougar is a swept-wing, higher performance model of the F9F-5, which, in turn, is a modification of the F9F-3. The Cougar is basically a Navy day fighter. The first flight of the prototype was in September, 1951. The wingspan is 34 feet 6 inches, the length is 40 feet 11 inches, the gross weight at maximum take-off about 17,900 pounds, the range about 1,000 miles, the maximum speed more than 650 miles per hour, and the armament four 20 mm. guns.

The powerplant is one Pratt & Whitney J-48-P-6A turbojet engine which delivers about 7,200 lb. thrust, but the Allison J-33 turbojet engine has been used in a few versions of the Cougar.

LOCKHEED F-80 SHOOTING STAR

The Lockheed F-80 Shooting Star, illustrated in Fig. 22, is no longer in production, but it is still flown by the U.S. Air Force and by the National Guard. During the war in Korea, it was modified for ground attack duties to carry two 1,000-pound bombs plus 8 rockets, or four forty-gallon Napalm fire bombs.

On extremely short fields the airplane can take off more quickly than normal by means of two 1,000-pound thrust RATO (Rocket-Assisted-Take-Off) packs under the fuselage.



Fig. 22. Lockheed F-80 Shooting Star.

AIRPLANES POWERED BY TURBOJET ENGINES

The F-80 is the pioneer of operational jet-propelled aircraft, because more pilots received their training on this airplane, and more was learned from it than from any other aircraft powered solely by jet propulsion. It was the first jet airplane to go into quantity production. It established many speed records and was the airplane which brought the world's speed record back to the United States in 1947 after 23 years, by flying at a speed of 623.8 miles per hour at Muroc, California. When the history of jet-propelled aircraft is written, the Lockheed F-80 Shooting Star must always be recognized as America's first great contribution to the new era of aviation.

LOCKHEED U.S. AIR FORCE RF-80, NAVY TV-1

The Lockheed U.S. Air Force RF-80 is a photo-reconnaissance version of the F-80 Shooting Star series. The TV-1 is the Navy designation for this same series of airplanes.

The wingspan is 38 feet 10 inches, the length 34 feet 6 inches, gross weight at take-off is a maximum of 15,736 pounds, the range is 1,200 miles, the maximum speed is more than 500 miles per hour, and the armament consists of six .50 caliber guns and bombs. The power plant is one J-33-A-35 Allison turbojet engine delivering about 5,200 pounds thrust. It has a pilot ejection seat and a canopy ejection mechanism.

LOCKHEED U.S. AIR FORCE T-33, NAVY TV-2

The Lockheed U.S. Air Force T-33, Navy TV-2, is a two-place airplane used primarily as a trainer for pilots assigned to jet fighters and for instrument training. It is a development of the F-80 Shooting Star. In service since 1948, the T-33 trainers are built for the U.S. Air Force, U.S. Marine Corps, and nine allied powers, including the Royal Canadian Air Force. Fig. 23 gives a breakdown drawing of this airplane, with the major parts called out in the table below.

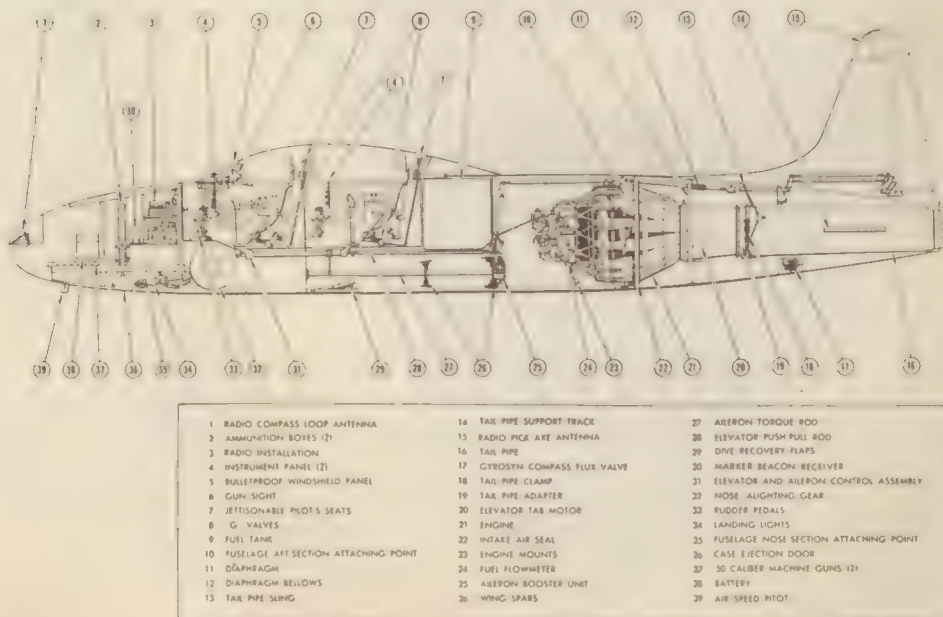


Fig. 23. Breakdown drawing of Lockheed's Air Force T-33 & Navy TV-2.

JET AIRCRAFT SIMPLIFIED

The wingspan is 37 feet 8 inches, the length is 38 feet 10 inches, the gross weight is 15,500 pounds, the range is 1,200 miles, the maximum speed is more than 500 miles per hour, and the armament can consist of six .50-caliber guns plus bombs. The powerplant consists of one J-33-A-35 Allison turbojet engine delivering a thrust of 5,200 pounds. Both front and rear cockpits have a jettisonable canopy and ejection seats.

LOCKHEED XF-90

The Lockheed XF-90, illustrated in Fig. 24, is a U. S. Air Force penetration fighter designed for high altitude and high speed operation. Its maximum speed is more than 600 miles per hour. The extremely thin wing profile and the 35° angle of sweepback represent major steps forward in the design of fighter aircraft. Two Westinghouse J34 turbojet engines are mounted side by side and determine the width of the fuselage, which is about 5 feet. The main fuel supply is in the fuselage and is supplemented by jettisonable fuel tanks at the extreme wing tips. This fuel capacity gives the airplane a range of more than 1,000 miles.



Fig. 24. Lockheed XF-90 in flight.

LOCKHEED F-94 STARFIRE

The single-seat Lockheed F-80 Shooting Star was lengthened three feet to become the two-place U.S. Air Force T-33, Navy TV-2, and then the T-33 (Navy TV-2) was lengthened 2.4 feet and provided with afterburners, guns, and electronic devices, to become the F-94A and F-94B interceptors, now also known as Starfires, which are listed as all-weather 24-hour interceptors. They were originally equipped with the Allison J-33-A-33 turbojet engine having a thrust of 5,200 pounds, and also equipped with an afterburner.



Fig. 25. Lockheed F-94 Starfire over Southern California.

JET AIRCRAFT SIMPLIFIED

The Lockheed U.S. Air Force F-94C Starfire is the first U.S. fighting plane to have an all-rocket armament. It carries 48 rockets of the 2.75-inch size, housed in a ring of firing tubes around the nose and in wing pods. Radar and specialized instruments enable the Starfire to locate the enemy miles away, follow the target, track, close, aim and open fire, almost entirely automatically. Its specific mission is to knock out invading bombers. Its Pratt & Whitney J-48-P-5 turbojet engine delivers a thrust of 6,250 pounds without the afterburner. With the afterburner in use, the F-94C can climb faster than any other American airplane.

The principal duties of the pilot and radar operator are to take the airplane off the ground, maneuver to the general target area as guided by ground radar watchers, switch on the "electronic crew" at the proper time, monitor operation of the piloting and rocket-control apparatus during the attack, and then land the airplane.

Fig. 25 shows the F-94C Starfire in flight. The two men ride in a pressurized, temperature-controlled cockpit provided with jettisonable canopy and ejection seats. The length is 41 feet 4 inches, the wingspan is 37 feet 6 inches, and the height is 13 feet 7 inches. A ribbon parachute in the tail compartment, released just as the airplane lands, can halt it in a short space. The top speed is listed as more than 600 miles per hour, which obviously is an understatement. This airplane has passed through the speed of sound in dives.

MCDONNELL FH-1 PHANTOM

The first U.S. Navy airplane made by McDonnell Aircraft Corporation, St. Louis, Missouri, was the FH-1 Phantom twin-jet fighter, which made aviation history in July, 1946, by being the first U.S. all-jet-propelled aircraft to take-off from and land on a U.S. carrier. This airplane is illustrated in Fig. 26 by a three-view line drawing. The original Phantom has been modified and production models have been flown by the Navy and Marine Corps.

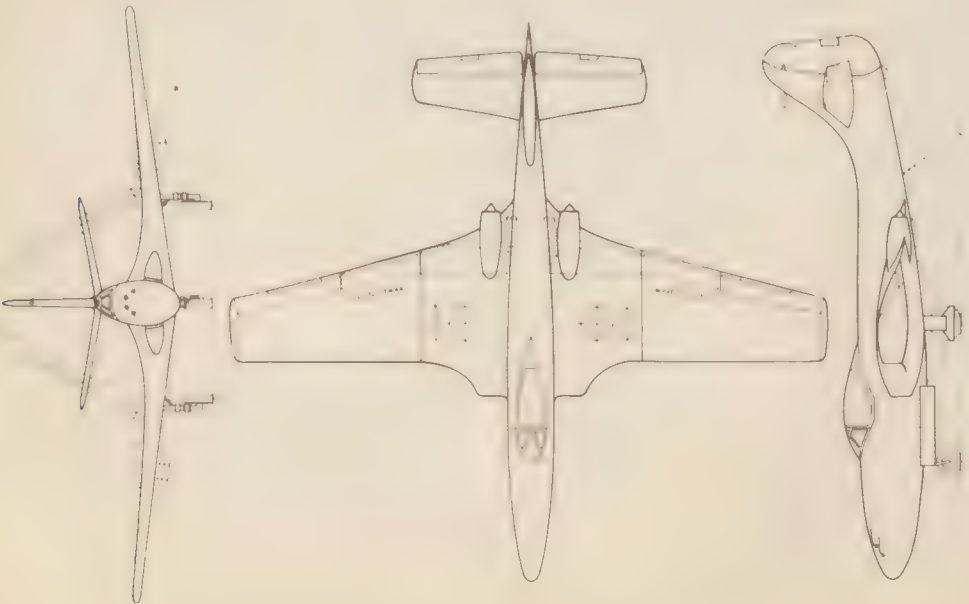


Fig. 26. A three-view drawing of McDonnell FH-1 Phantom.

AIRPLANES POWERED BY TURBOJET ENGINES



Fig. 27. McDonnell F2H-1 Banshee over North Korea.

MCDONNELL F2H-1 BANSHEE

The McDonnell F2H-1 Banshee entered production in 1947, as a single-seat, two-engine, turbo-jet propelled fighter, designed to be based on either land or sea. Its first flight was on August 10, 1948. The wingspan was 41 feet 8 inches, the length was 39 feet, the gross weight was a maximum over 14,000 pounds for take-off, the maximum speed was more than 600 miles per hour, and the armament consisted of four 20 mm. guns. The powerplant consisted of two Westinghouse J34-WE-30 turbojet engines having a rating then of more than 3,000 pounds thrust each.

Fig. 27 shows a Banshee just after it had taken off from the aircraft carrier USS Essex to scour a North Korean sector in search of targets. The detail designs of the different F2H Banshee series of airplanes are outlined in the following paragraphs. However, the general shape and configuration is the same for the F2H-1, -2, -2P and -3.

JET AIRCRAFT SIMPLIFIED

MCDONNELL F2H-2 BANSHEE

The F2H-2 Banshee is a single place, two engine, jet-propelled, long range, Navy fighter, incorporating droppable tip tanks. It was designed to be either land-based or carrier-based. The first flight was August 18, 1949. The F2H-2n is a night-fighter version of the F2H-2, also designed to be either land-based or carrier-based. The wingspan is 44 feet 11 inches, the length 40 feet 10 inches, the maximum gross weight for take-off is up to 20,000 pounds, the range is more than 1,500 miles, the maximum speed is in the 600 miles-per-hour class, and the armament consists of four 20 mm. guns plus bombs or rockets. The airplane is powered by two Westinghouse J34-WE-34 turbojet engines.

MCDONNELL F2H-2P BANSHEE

The F2H-2p Banshee is a single-place, two-engine, jet-propelled, long-range fighter equipped for photographic reconnaissance. It is designed to be either land-based, or carrier-based. The wingspan is 44 feet 11 inches, the length 43 feet, the maximum gross weight for take-off is more than 20,000 pounds, the range more than 1,500 miles, and the maximum speed above 550 miles per hour. The power-plant consists of two Westinghouse J34-WE-34 turbojets, each having a rating of more than 3,000 pounds thrust.

MCDONNELL F2H-3 BANSHEE

The F2H-3 Banshee is a carrier-based airplane with a fuselage longer than that of the F2H-2. It is an all-weather fighter with greatly improved radar equipment, more armament, greater fuel supply, and other improvements over earlier models.



Fig. 28 Ground view of McDonnell F3H-1 Demon.

AIRPLANES POWERED BY TURBOJET ENGINES

MCDONNELL F3H-1 DEMON

The McDonnell F3H-1 Demon, illustrated in Figs. 28 and 29, is a single-seat, swept-wing, carrier-based fighter which is used by the Navy. The original power plant was one Westinghouse turbojet engine. Armament has been increased and also the engine power. The present performance exceeds that of the FH-1 and F2H.

SPAN 35' 4"

LENGTH 59' 4"

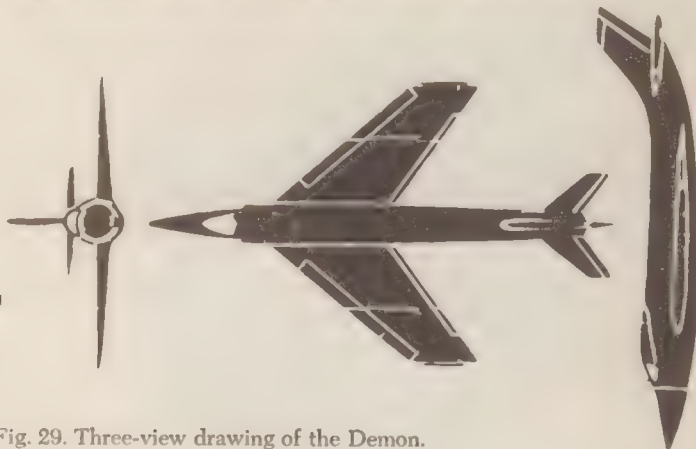


Fig. 29. Three-view drawing of the Demon.

MCDONNELL F-85 GOBLIN

The McDonnell F-85 Goblin, illustrated in Fig. 30, is a U.S. Air Force jet "parasite" fighter designed to ride in the belly of the Consolidatde Vultee B-36 airplane and to provide fighter protection for the mother airplane on long missions. The Goblin can be lodged in the bomb bay of a B-29, such as that used for its first test flights. After completing its mission, the Goblin re-engages the trapeze—in flight—and is drawn back into the bomb bay.



Fig. 30. McDonnell XF-85 Goblin.

JET AIRCRAFT SIMPLIFIED

MCDONNELL F88-A VOODOO

The McDonnell U.S.A.F. XF88-A Voodoo is a land-based penetration fighter designed for supersonic operations. The span is 40 feet, the length 55 feet, and the height about 15 feet. The maximum gross weight is more than 20,000 pounds. The wings are swept back at an angle of 35 degrees. The airplane has a pressurized interior and refrigerated cabin. It is equipped with an automatic yaw dampener and other automatic control equipment. It has a high rate of climb and a long range. The powerplant consists of two Westinghouse J-34 turbojet engines delivering a thrust with afterburners of more than 4,000 pounds each. The speed is more than 660 miles per hour. Fig. 31 is a drawing of the Voodoo on the ground.



Fig. 31. McDonnell XF 88-A Voodoo.

MARTIN TEST OF ENGLISH CANBERRA

Fig. 32 shows the English Electric Canberra, a twin jet light bomber, as it passes over the Chesapeake Bay Bridge, not far from the home plant of The Glenn L. Martin Company, Middle River, Baltimore, Maryland. The Canberra was being flight-tested by The Glenn L. Martin Co., which has built a night-intruder version of the Canberra for the U.S. Air Force. The Martin-built airplane is the same essentially as the Royal Air Force Canberra, but powered with Wright J-65 Sapphire engines instead of Rolls Royce Avons. The airplane illustrated held the record for an East-West Trans-Atlantic crossing, 4 hours, 19 minutes, from Northern Ireland to Newfoundland, established on August 31, 1951.



Fig. 32. The English Cambera over Chesapeake Bay.

JET AIRCRAFT SIMPLIFIED

MARTIN B-57 NIGHT INTRUDER

Fig. 33 is a three-view line drawing of the Martin B-57-A. This is a twin-jet night intruder and has about the same size and shape as the English Electric Canberra, but the interior of the B-57 was re-designed to accommodate a great mass of electronic equipment. The B-57A is powered by two Wright Sapphire J-65 engines. The design of the airplane is fairly conventional, considering that it is a high-speed jet job. It has a straight, broad wing and a conventional landing gear. The span is about 65 feet and the length is 64 feet. The crew consists of two men.

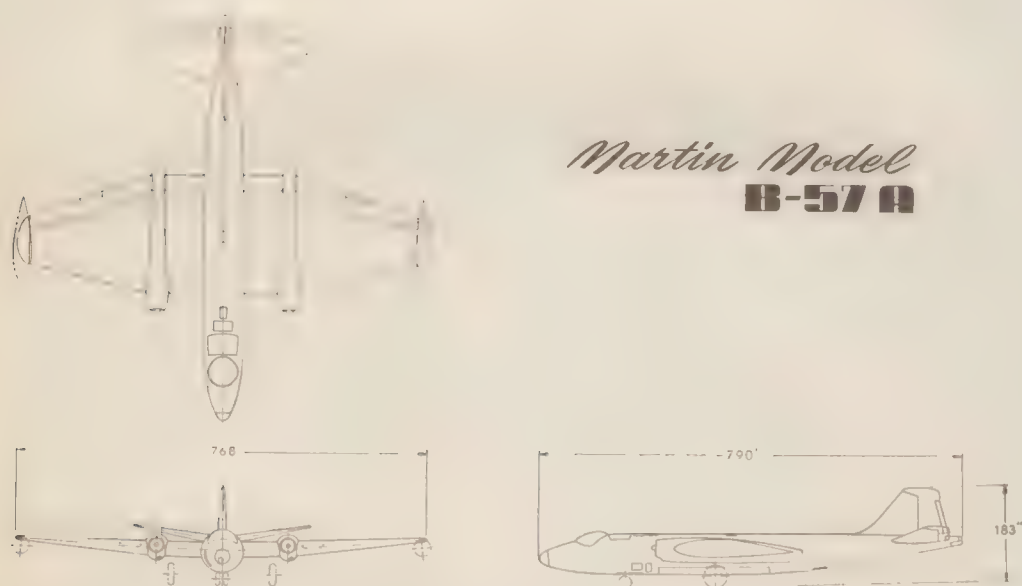


Fig. 33 A three-view drawing of the Martin B-57-A night intruder.

MARTIN XB-51 GROUND-SUPPORT BOMBER

The Martin XB-51 Ground Support Bomber is illustrated by a photograph of the airplane on the ground in Fig. 34 and by a three-view line drawing in Fig. 35. This is the U.S. Air Force's first three-jet bomber and the first airplane specifically designed for ground support. Two General Electric J-47 turbojet engines are mounted on pylons below the cockpit on the airplane's sides and the third is in the tail, with the aircoop on top of the fuselage.

The wings and stabilizers are swept back at an angle of 35 degrees. Dual wheels are mounted tandem style and retract into the fuselage. The balance for taxi purposes is provided by two small outrigger wheels near the wing tips. The span is about 55 feet, the length about 80 feet. The two-man crew consists of the pilot and the navigator-bombardier.



Fig. 34. Ground view of Martin XB-51 ground-support bomber.

JET AIRCRAFT SIMPLIFIED

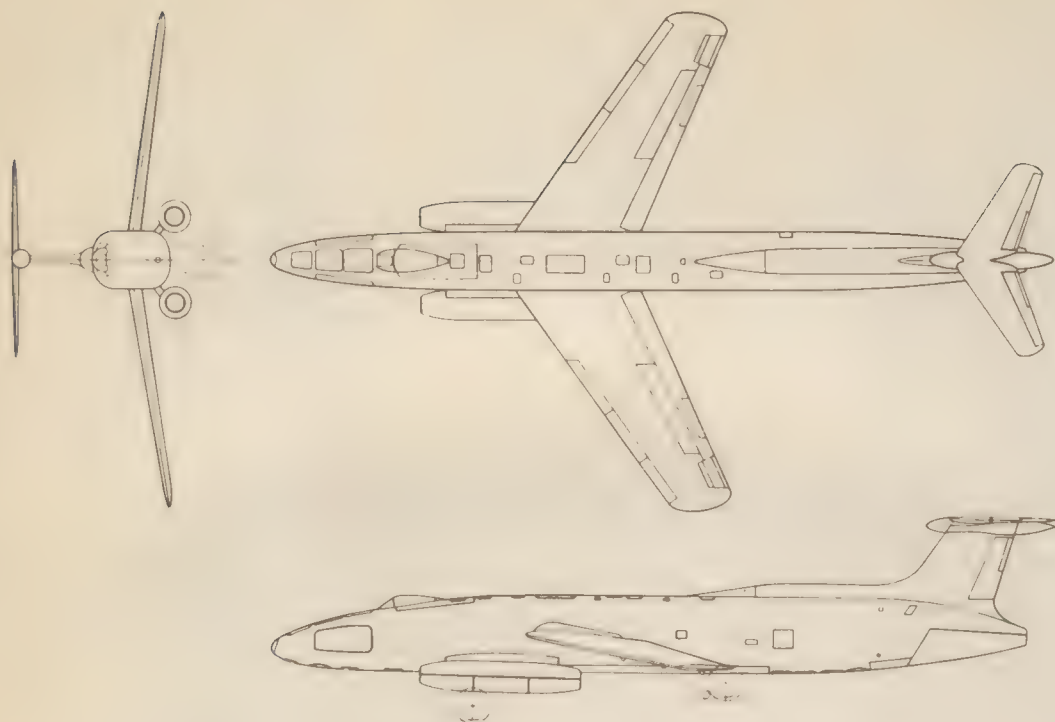


Fig. 35. A three-view drawing of the Martin XB-51.

THE MARTIN P4M-1 MERCATOR

The P4M-1 Mercator, made by the Glenn L. Martin Co., illustrated in Fig. 36, is a Navy bomber which appears to be only a two-engine airplane, but it has four power plants, an Allison J33-4 jet engine being mounted aft and in the same nacelle with each of two conventional Pratt & Whitney R-4360-4 engines. The gross take-off weight is more than 75,000 pounds. The top speed with all four engines is more than 350 miles per hour, and the maximum range is more than 3,000 miles. The wing span is 114 feet, the length is 82½ feet, and the normal crew consists of eight men.

MARTIN XP6M-1 SEAMASTER

The Glenn L. Martin Company is building for the Navy an experimental jet-powered seaplane designated the XP6M-1, and called by its designers the SeaMaster. Further information is not released.

NORTH AMERICAN F-86 SABRE

The North American Sabre, known to the U.S. Air Force as the F-86, made by North American Aviation, Inc., Los Angeles, California, was the first United States fighter designed with sweptback wings and tail unit. Fig. 37 is a three-view line drawing of the F-86D. Fig. 38 shows the airplane on the ground with the



Fig. 36. Martin P4M-1 Mercator.

JET AIRCRAFT SIMPLIFIED

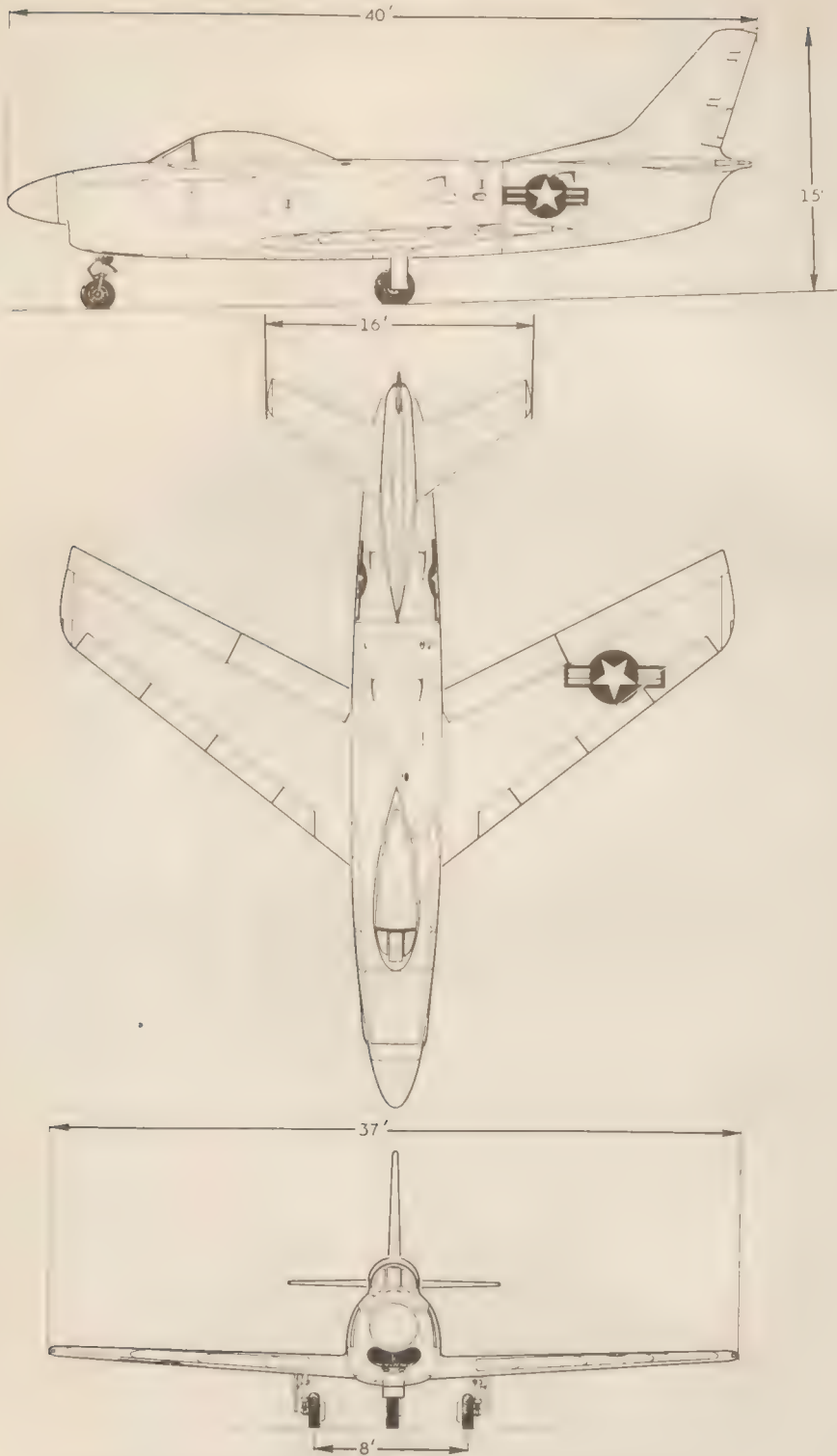


Fig. 37. A three-view drawing of the North American F-86 Sabre.



Fig. 38. The rocket "package" shown below the fuselage of the Sabre.

JET AIRCRAFT SIMPLIFIED

rocket "package" installed, which retracts into the fuselage. From this package, the airplane can fire twenty-four 2.75-inch "Mighty Mouse" rockets. A hit from a single rocket can knock out a heavy bomber.

The F-86 established a world speed record of 715.697 miles per hour over the Salton Sea, near Palm Springs, California, July 16, 1953.

The F-86D is a high-altitude, all-weather interceptor which can operate day or night to defend against enemy air attack. The pilot, without ever seeing an enemy airplane except as a smear or "blip" on his radar scope, can fire his rockets with great accuracy. Immediately after firing the rockets, the pod snaps back into the airplane, giving it a streamlined surface for flight at speeds at or near the speed of sound.

The F-86D, the F-86E, and the F-86F have all been powered with the General Electric J-47 turbojet engine with the "D" model having an afterburner. The thrust rating, without the afterburner, of the F-86D is more than 5,200 pounds.



Fig. 39. North American test pilot in Air Forces's T-1 space suit.

AIRPLANES POWERED BY TURBOJET ENGINES

The wings of the Sabre models are swept back 35 degrees to provide higher speed but with a greater lifting area. The "D" model has a 37-foot wing span and a height of 15 feet, like earlier models, but it is 3 feet longer than the 37-foot length of the earlier versions.

Fig. 39 is a photograph of George Welch, senior test pilot of North American Aviation, Inc., ready for a test flight high above Los Angeles where his body would burst like an overly ripe tomato if he were forced to bail out and if he did not wear the U.S. Air Force's T-1 space suit. Welch was the first man to fly the F-86D Sabre. Each of the special high-altitude test suits, similar to that worn by Welch, is tailor made by the Air Force to fit each research pilot. The suit worn by Welch was made at a cost of about \$25,000, covering both design and production items, so that he can have his body protected from the severe pressures that he is subjected to at altitudes above 40,000 feet.

NORTH AMERICAN F-100 SUPER SABRE

The newest of North American's jet fighters is designated as the F-100. Although performance details of this new plane are restricted, the Air Force has announced that it has already completed its first flight tests at Edwards Air Force Base, Muroc, California. This "Super Sabre" is officially rated as a supersonic fighter, and is being powered by Pratt & Whitney's newest jet engine, the J-57.

NORTH AMERICAN RB-45C TORNADO

The North American Aviation RB 45-C Tornado is a long-range, special-mission, high-speed, high-altitude, four-jet, photo-reconnaissance bomber, which is a later version of the U.S.A.F. B-45 Tornado four-jet bomber. Equipped with five camera stations, it serves as a flying mapmaking machine. It can fly day and night reconnaissance at high and low altitudes, charting, mapping, and photographing terrain, installations, and other objects of military or economic importance. Fig. 40 shows the B-45C as a bomber, carrying a payload of more than ten tons. The black paint on the inside of the tanks and engine nacelles is to reduce glare.

The Tornado is powered by four General Electric J-47-A turbojet engines, each with a thrust of 5,200 pounds, hence the total thrust is 20,800 pounds. The speed is more than 550 miles per hour. The use of alcohol-water injection makes added power available for take-off. With a maximum gross weight of 110,000 pounds, the RB-45C has a service ceiling of more than 40,000 feet and a normal tactical radius of more than 1,200 miles, making use of the wing-tip tanks. Bomb-bay tanks can be used to increase the range even more. Automatic fuel selectors help the pilot by drawing from the airplane tanks evenly, equalizing the airplane balance as fuel is consumed.

The Tornado has a crew of three: Pilot, co-pilot, and a photographer-navigator. The pilot and co-pilot sit in tandem in a pressurized cockpit, with dual flight controls to permit the co-pilot to act as relief or emergency pilot. The photographer-navigator also acts as bombardier and radar operator. Catapult ejection seats for the two pilots, and an escape hatch for the photographer-navigator, provide means for emergency abandonment of the airplane. The Tornado has a wing span of 89 feet, it is 76 feet long and 23 feet high.

JET AIRCRAFT SIMPLIFIED

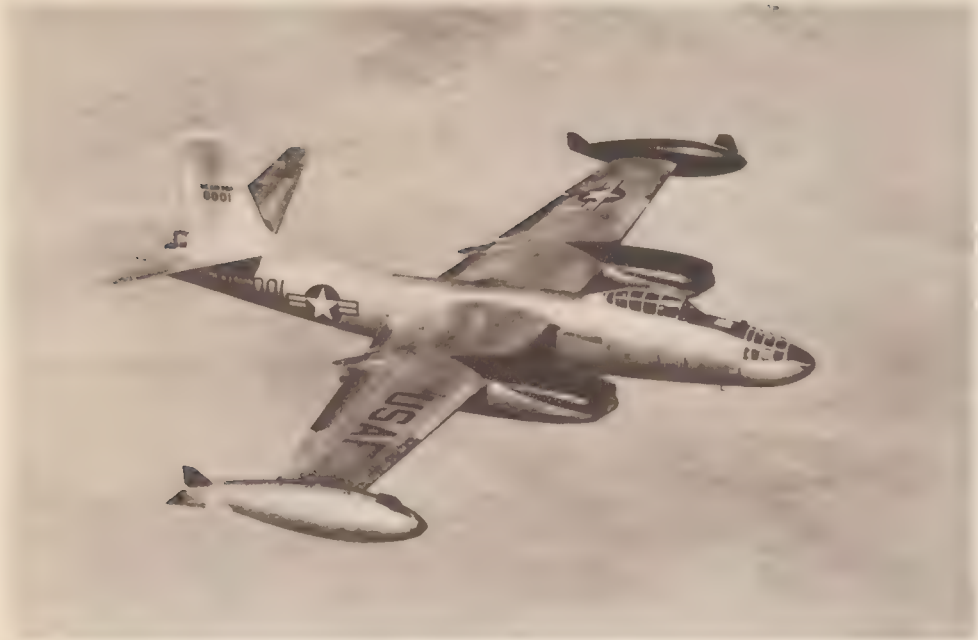


Fig. 40. North American RB-45C Tornado.

NORTH AMERICAN AJ-1 SAVAGE

The North American Aviation AJ-1 Savage, built for the U.S. Navy, is shown in flight in Fig. 41, where it is being used as an aerial tanker to refuel a Navy Grumman F9F. The AJ-1 Savage is a large, composite-powered carrier-based attack bomber which can carry an atomic bomb to an enemy target. Designed primarily as a high-speed attack airplane, it combines both piston-engine and turbojet-engine power. Droppable auxiliary fuel cells carried in the bomb bay of the tanker can be used to carry the additional fuel required for refueling other airplanes.

The AJ-1 Savage tanker uses the British-developed probe and drogue method of refueling which permits the pilot of the receiving airplane to choose the time of contact. His airplane has a lance-like attachment and like a jousting knight he aims at a funnel-like device extended on a flexible hose from the tanker. The pilots of both the airplane delivering and the airplane receiving the fuel can "check out" on the technique in one flight. This system differs from the "flying boom" method used on some airplanes wherein a boom operator in the tanker airplane guides the refueling hose into the receiving airplane.

The Navy believes that the tactical advantages gained by mid-air refueling of relatively short-range fighters are sufficiently important to justify airplanes equipped for this practice. In this manner, long-range offensive missions can be escorted all the way to and from target areas without facing the fuel-shortage problem. Combat air patrols can be maintained continuously for long periods, cancelling former frequent launching and retrieving requirements by the Navy carrier task force. Armament loads of fighter aircraft also can be increased.

AIRPLANES POWERED BY TURBOJET ENGINES

The AJ-1 Savage is powered by two Pratt & Whitney R-2800 reciprocating engines located under the wings and a single Allison J-33 turbojet engine mounted in the aft section of the fuselage. A crew of three men operate the airplane.

NORTH AMERICAN AJ-2 SAVAGE

The North American-Navy AJ-2 Savage is a carrier-based Navy bomber built by North American Aviation, Inc., at Columbus, Ohio. It can carry and deliver an atomic bomb from either a carrier or a land station. External changes in the AJ-2 which differ from the AJ-1 include a higher vertical stabilizer and a horizontal stabilizer without dihedral. The fuselage is about two feet longer. Internally, the cockpit has been rearranged to provide one large compartment for the three-man crew instead of the two smaller compartments in the AJ-1. The wing span of the AJ-2 is about 75 feet, the total length is more than 65 feet, the airplane is 21 feet high, and it weighs about 25 tons. It has folding wings and a vertical stabilizer to facilitate handling and storage below decks on carriers of the Midway class.

The reciprocating and jet engines burn the same fuel to reduce complexity of design and fuel supply. The AJ-2 is powered by two Pratt & Whitney R-2800 reciprocating engines, and an Allison J-33 turbojet engine, which is located in the aft section of the fuselage. It is used for added power for take-offs, landings, and over a target area. The reciprocating engines turn four-bladed Hamilton standard propellers. The upper speed is about 425 miles per hour.

NORTH AMERICAN AJ-2P SAVAGE

The North American-Navy AJ-2P Savage is a photographic-reconnaissance version of the AJ-2, manufactured at Columbus, Ohio, by North American Aviation, Inc. Space is provided for eighteen cameras for both night and day photography at all altitudes. Photo-flash bombs are used in the bomb bay for night operations. Most of the cameras are automatically controlled. The maximum weight and speed is approximately the same as for the AJ-2.



Fig. 41. North American AJ-1 Savage.

JET AIRCRAFT SIMPLIFIED

NORTH AMERICAN FJ-2 FURY

The Navy FJ-2, made by North American Aviation, Inc., at Columbus, Ohio, and called the *Fury*, is a single-seat, swept-wing, carrier-based, high-performance fighter, which was developed from the FJ-1. In Fig. 42 it is shooting off the deck of the U.S.S. Coral Sea, after it was launched from the carrier's catapult.

The wingspan is 37 feet 1 inch, the length is 37 feet 7 inches, the maximum gross weight for take-off is up to 18,800 pounds, the range is more than 1,000 miles, the maximum speed is more than 650 miles per hour, and the armament consists of four 20 mm. guns. The powerplant is one General Electric J-47-GE-2 turbojet engine, having a thrust of more than 5,800 pounds. The service ceiling of the airplane is more than 45,000 feet.

A previous model, called the FJ-1, was the Navy's first operational carrier-based jet fighter. In the newer version, the landing gear is similar to that of the F86 Sabre Jet but the nose-wheel unit is made so that the airplane is better adapted for catapult launching. Another noticeable difference between the FJ-1 and the FJ-2 is that the latter has a 35-degree sweptback wing and tail. It also has hydraulic powered irreversible controls, with artificial feel, for the all-movable horizontal stabilizer and ailerons found on the F-86E Sabre Jet and later North American models.



Fig. 42. North American FJ-2 Fury just taking off carrier.

NORTHROP F-89D SCORPION

The Northrop Scorpion, known to the U. S. Air Force as the F-89D, is the principal product of Northrop Aircraft, Inc., Hawthorne, California, about which information can be published. Fig. 43 shows the general arrangement of this airplane, and Fig. 44 shows the Scorpion firing rockets at night.

The F-89D is a heavily armed, high-altitude, mid-wing, twin-engined, jet-propelled, all-weather, U. S. Air Force interceptor, manned by a crew of two, a pilot and a radar observer, seated tandem in pressurized cockpits enclosed by a single jettisonable canopy. Ejection seats are provided for both crew members.



Fig. 43. A phantom view of the Northrop F-89 Scorpion.

JET AIRCRAFT SIMPLIFIED



Fig. 44. The Scorpion firing rockets at night.

The horizontal stabilizer is located halfway up the vertical stabilizer, placing it above the hot gases emitted from the twin-jet exhausts and diminishing the effect of the turbulence caused by the flow of air over the wing. Its primary mission is the protection of the continental United States against invading aircraft.

This airplane is powered by two Allison J-35 turbojet engines, each of which has a static (dry) thrust of 5,600 pounds, and has an afterburner with an adjustable nozzle. The engines may be lowered clear of the mountings by a hydraulic hoist built into the airplane for maintenance. The engines are mounted on each side of the fuselage keel partly inside the contour of the fuselage and very low.

The speed is more than 600 miles per hour and the altitude is above 45,000 feet. Electronic equipment of an advanced design enables the pilot and radar observer to hit enemy aircraft regardless of darkness or bad weather. Fig. 45 is an artist's conception of the manner in which invisible radar waves are out from the nose of the Northrop Scorpion F-89, seek out the enemy, rebound, and are then picked up by the Scorpion's radar and shown as "blips" on the radar screen in the airplane. The Scorpion can then close in on the enemy airplane and destroy it.



Fig. 45. Artist's conception of Scorpion's radar equipment seeking out the enemy.

JET AIRCRAFT SIMPLIFIED



Fig. 46. Northrop X-4, U. S. Force research airplane.

NORTHROP X-4, U.S. AIRFORCE RESEARCH AIRPLANE

Fig. 46 shows the Northrop X-4, a U. S. Air Force research airplane on the ground. This is a twin-jet, single-seat, swept-wing, lance-shaped, semi-tailless, Flying-Wing type; research monoplane, one of the smallest airplanes ever built for the U. S. Air Force. It is about twenty feet long and has a wing span of about 25 feet. Its controls are patterned after the famous Northrop Flying Wing, in that it uses "elevons" built into the trailing edge of the wing to serve as both ailerons and elevators, while a single vertical fin and rudder provide lateral stability and control.

It has been powered by two Westinghouse J-30 turbojet engines located in the wing roots, near the fuselage, but this particular type, make, and model of engine is not necessarily the one in current use.

It can maintain flights of comparatively long duration. It is not intended to travel at supersonic speeds, but rather it is designed to explore the flight characteristics of aircraft in the subsonic zone near the speed of sound.

The X-4 made its first test flight from Muroc Air Force Base in the California desert. Elaborate N.A.C.A. instrumentation records the results of all tests on this airplane.

AIRPLANES POWERED BY TURBOJET ENGINES

REPUBLIC F-84 THUNDERJET

The Republic Thunderjet, known to the U. S. Air Force as the F-84, has been built in a series of versions, beginning with the prototype XF-84, flown on February 28, 1946, followed by the F-84-B, and so on through the alphabet to the F-84-G Thunderjet, a flight view of which is shown in Fig. 47. This version was powered with one Allison J-35-A-17 turbojet engine, rated as having a 5,000 pound thrust.



Fig. 47. Republic F-84 Thunderjet.

REPUBLIC F-84F THUNDERSTREAK

The Republic Thunderstreak, known to the U.S.A.F. as the F-84F, is manufactured by the Republic Aviation Corporation, Farmingdale, Long Island, New York. It is a swept-wing, single-seat, high-speed, fighter-bomber. The span is 33 feet 6 inches, the length is 43 feet 4 inches, the height is 14 feet 4 inches at rudder tip, the speed is more than 600 miles per hour, the range is more than 1,000 miles (combat radius), the service ceiling is more than 45,000 feet, and the armament consists of six .50-caliber machine guns, plus externally mounted rockets, bombs and napalm. The powerplant is one Wright Sapphire J-65 turbojet engine developing about 7,200 pounds thrust and made by Wright Aeronautical Company and the Buick Division of the General Motors Corporation.

Fig. 48 is a cutaway drawing of the F-84F Thunderstreak, to indicate the complexity of this and other jet aircraft. It is a mid-wing type of airplane with wings and tail swept back at an angle of 40 degrees. A new feature of the F-84F is its faired-back canopy, designed to blend into the rear half of the fuselage. This canopy provides better pilot visibility and more streamlining for speed.

Fig. 48. A cutaway drawing of Republic F-84F Thunderstreak.

This cutaway drawing of Republic's Thunderstreak indicates the complexity of modern jet fighter planes.

- | | |
|--------------------------------------|--------------------------------------|
| (10) GUN DECK INSTALLATION | (10) COMPLETE REAR END |
| (11) AIR INTAKE DIVIDER | (11) AIR INTAKE DIVIDER |
| (12) LANDING GEAR ACTUATING CYLINDER | (12) LANDING GEAR ACTUATING CYLINDER |
| (13) SHOULD COOLING INLET | (13) SHOULD COOLING INLET |
| (14) ENGINEER TANK | (14) ENGINEER TANK |
| (15) VERTICAL FIN ASSEMBLY | (15) VERTICAL FIN ASSEMBLY |
| (16) NOSE BEAM ASSEMBLY | (16) NOSE BEAM ASSEMBLY |



AIRPLANES POWERED BY TURBOJET ENGINES

REPUBLIC RF-84F THUNDERSTREAK, PHOTO RECONNAISSANCE FIGHTER

The Republic Thunderstreak, U.S.A.F. RF-84F Photo Reconnaissance Fighter is a sister ship of the F-84F Thunderstreak fighter-bomber. It is a high-speed, high or low altitude, day or night photo-reconnaissance airplane built by the Republic Aviation Corporation to meet the U. S. Air Force's requirements for a high-speed photographic airplane capable of getting the pictures of the enemy installations and getting them safely and promptly back to the base. It mounts four .50-caliber machine guns, two in each wing, to fight its way in and out of enemy territory, when it must. The nose section, which is larger and less pointed than the F-84F, carries aerial cameras in varying combinations. This airplane is powered by a "Sapphire" turbojet engine built both by Wright and Buick which delivers 7,200 pounds thrust.



Fig. 49. Republic F-84G Thunderjet.

REPUBLIC F-84G THUNDERJET

The Republic F-84G, Thunderjet, was the first production-line jet fighter equipped for mid-air refueling and also the first *fighter* to be designated by the U. S. Air Force to carry an atomic bomb. Fig. 49 shows it on the ground. In Fig. 50, the F-84G Thunderjet is making a mid-air refueling contact with a Boeing KB-29 tanker (upper airplane in picture), using the Boeing-type flying-boom system. In Fig. 50, the Thunderjet has four 230-gallon external fuel tanks which give it a 1,000-mile radius of combat.

JET AIRCRAFT SIMPLIFIED



Fig. 50. Thunderjet being refueled in mid-air.

The F-84G is 38 feet long, 12 feet 6 inches high, has a wing span of 36 feet, can fly more than 600 miles per hour, has a service ceiling of more than 45,000 feet, has a radius of action of 850 miles with two external fuel tanks, has a radius of action of 1,000 miles with four external fuel tanks, and can extend the range greatly by means of mid-air refueling. The armament consists of six M3-type .50-caliber machine guns. It carries up to 4,000 pounds of external armament, such as rockets, 1,000-pound bombs, napalm tanks, or a combination of armament and fuel.

The powerplant is one Allison J-35 turbojet engine delivering a thrust of 5,600 pounds.

In the flying-boom type of refueling used in this airplane, an operator in the tail of the tanker airplane operates a telescoping boom with directional control surfaces to guide the boom into the wing receptacle of the close-flying fighter. After the boom nozzle engages the fighter, fuel transfer becomes automatic.

CHAPTER IX

GUIDED MISSILES & PILOTLESS AIRCRAFT

ROCKET-POWERED GUIDED MISSILES

The usual dictionary definition of a *rocket* describes it as a firework consisting of a cylindrical case containing a combustible composition and fastened to a guiding stick, projected through the air by the reaction of gases liberated by combustion.

An encyclopaedia, or even a large dictionary, usually says that rockets in warfare are used for signaling, setting fire to enemy buildings or shipping, and as projectiles. Whatever reference work you consult will then go on to explain that the flight of rockets is irregular, but that they are often effective against a savage enemy, and may be of some value in scaring horses, throwing mounted troops into disorder, or in bombarding troops on a hostile shore before the regular artillery can come into play.

All of these statements represent the ideas held by practically all civilians and all but a tiny handful of military authorities until the advent of World War II. The rocket has been all these things, but it has been much more in the past than most people realized and it has possibilities for the future which are breathtaking in their implications.

In attempting to define a rocket, we start with the fact that it is something capable of being thrown or projected, hence, for most purposes, it is a *missile*. Since it can be guided at least during the first stage of its flight path, it is usually a *guided missile*. However, it is propelled at high speed by the rearward expulsion of gases generated by the combustion of an internally carried fuel. In doing this, it follows Newton's third law of motion: "For every action, there is an equal and opposite reaction." The action of gases from the burning fuel, in pushing rearward out of the rocket, is matched by an equally forceful reaction which pushes the rocket in a forward direction opposite to that of the flow of gases.

It is this reaction force which causes a rocket to fly through the air. It is *not* the push of the escaping gases against the atmosphere. A rocket can operate in a vacuum. In fact, it flies faster in thin air because there is less atmospheric resistance. These principles hold equally valid with the simple Fourth of July rocket and the German V-2.

Rockets are a special branch of the jet-propulsion family. The German V-2 was a true rocket that carried within itself, in a separate tank, the oxygen required for the combustion of its liquid fuel. American military rockets used in World War II were also true rockets because they carried their own oxygen with them, although not in a separate tank. They were propelled by solid fuels, such as smokeless powders, containing the oxygen required for combustion.

With these preliminary discussions, we can define a rocket thus: *A rocket is a reaction or thermal-jet engine that carries its own oxygen and obtains its thrust from the discharge to the rear of the gaseous products of combustion.*

JET AIRCRAFT SIMPLIFIED

Remember, the athodyd, the pulsejet, the turbojet, and the propjet are all thermal-jet engines, and they all work by reaction, but all of them must depend upon the outside atmosphere for their oxygen, whereas the true rocket carries its own oxygen.

AN ELEMENTARY ROCKET ENGINE

Fig. 1 is a schematic drawing of an experimental rocket engine. The fuel is carried in a tank, just as it is in a conventional airplane. There is a supply of oxygen in liquid form. When liquid fuel is burned, gasoline, alcohol, and other common fuels having high heat energy can be used, although extensive research is being conducted in an effort to find more efficient fuels.

The fuel flows from the tank and serves as a coolant as it passes through the outer jacket of the engine and into the combustion chamber. Here it mixes with oxygen. A violent explosion takes place continuously. The hot gases formed by the explosion leave through a nozzle to the rear. This nozzle corresponds to the hole in the metal sphere mentioned in the description of the operating principle of other jet engines in the earlier chapters of this text.

When the explosion begins, there is pressure at all points on the inside of the combustion chamber of our rocket engine except at the nozzle, where the gases have no opposition and can escape. All of the forces acting on the inside of the rocket combustion chamber cancel or counteract each other except those forces acting on the inside of the chamber directly opposite the exhaust nozzle area. On the side away from the nozzle there is positive pressure.

The gases can escape at the nozzle, but the pressure there is extremely low and may be zero. As a result, the rocket moves in the direction of positive pressure, away from the nozzle. This is simply a matter of internal pressure inside the combustion chamber. Nothing outside has any effect on what happens inside.

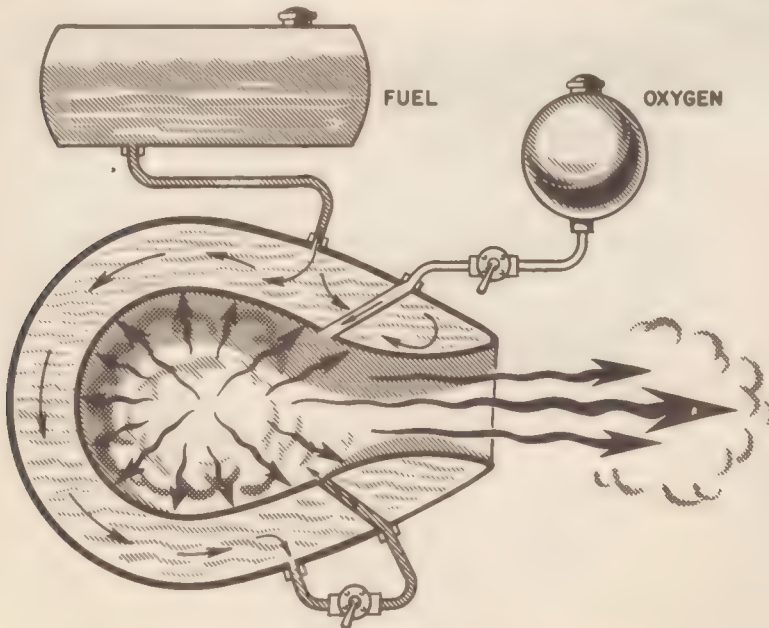


Fig. 1. A schematic drawing of an experimental rocket engine.

GUIDED MISSILES & PILOTLESS AIRCRAFT

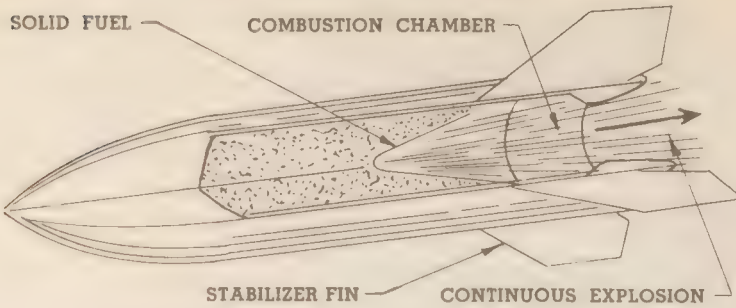


Fig. 2. A rocket which uses solid fuel.

BASIC ROCKET CONSTRUCTION

Fig. 2 shows a rocket which uses solid fuel, such as gun powder, which burns constantly and causes a forward thrust on the projectile. One arrow points to the fuel, another arrow indicates the combustion chamber, and a third represents the gases rushing to the rear at the exhaust nozzle.

Fig. 3 shows a rocket which uses liquid fuel. Arrows point to the fuel tanks, combustion chamber, and main fuel line. Another arrow represents the exhaust thrust.

Fig. 4 is another rocket using liquid fuel. Arrows point to the fuel tanks, fuel pump, combustion chamber, stabilizer fin, and main body. The exhaust thrust is represented by an arrow drawn to the rear, as in the other drawings. Notice that the rockets in Figs. 2 and 4 have stabilizing fins but the one in Fig. 3 has none.

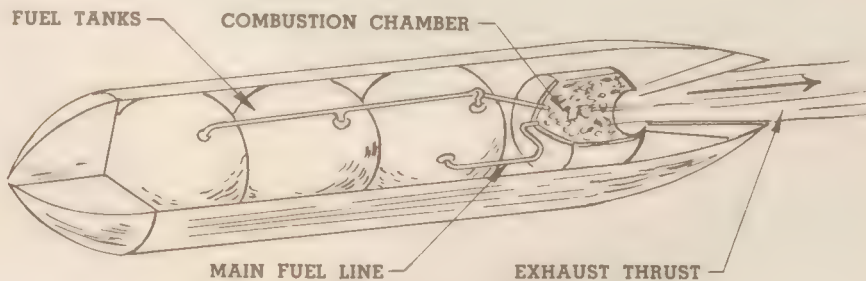


Fig. 3. A rocket which uses liquid fuel.

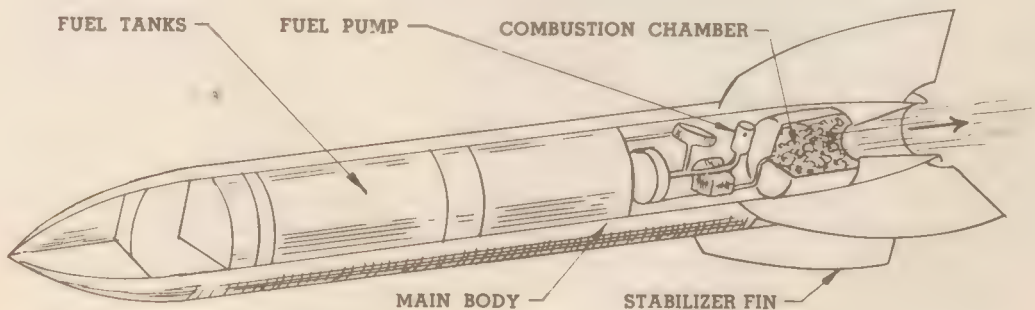


Fig. 4. Another rocket which uses liquid fuel.

JET AIRCRAFT SIMPLIFIED

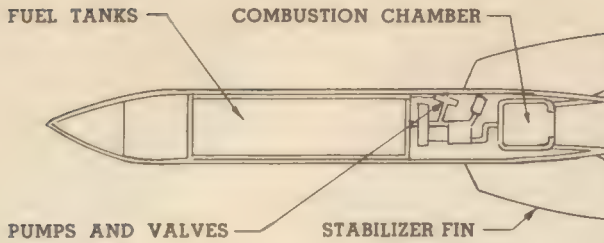


Fig. 5. A simplified drawing of a rocket which burns liquid fuel.

Fig. 5 is a simplified drawing of a rocket which burns liquid fuel. Arrows point to the fuel tanks, pumps and valves, and combustion chamber. Notice that this rocket has stabilizer fins like those in Figs. 2 and 4.

FUEL

A wide variety of chemicals have been used for fuel. All fuels may be classified as either *monopropellant* or *multipropellant*. For example, nitromethane is a monopropellant fuel because it can be used by itself. On the other hand, nitric acid and aniline can be used only in combination, hence the two constitute a multipropellant fuel, or, to be more specific, they form a *bipropellant* fuel, since there are only two chemicals involved, whereas a *multipropellant* may be a combination of two or more. In the case of multipropellants, each of the constituent chemicals is injected separately and in most cases combustion takes place immediately upon their contact with one another.

In many liquid-fuel rockets, the fuel flows through jackets made integral with the case of the rocket in order to serve as a coolant. Since the case may be very hot from the combustion of fuel and from friction with the atmosphere as it flies through the air at great speed, the liquid fuel may be vaporized and this contributes to its speed of combustion.

THE NEED FOR COOLING

The rocket combustion chamber may have to withstand temperatures of 4,000° F. to 6,000° F., and the nozzle may have to withstand the same temperatures and at the same time withstand velocities of the hot exhaust gases up to 8,000 feet per second. Some rockets designed for short flights have been constructed without any special cooling system, but cooling is an absolute requirement for long-duration flights if the engine is to avoid getting so hot that it will melt its mountings and set fire to the aircraft or missile in which it is installed.

METHODS OF COOLING ROCKET ENGINE WALLS

The combustion chambers of a rocket engine become so hot that it is impossible to operate the engine without providing a cooling system. Depending upon the type of liquid fuel used, one of the liquids is circulated or injected along the walls to keep the temperature within satisfactory limits.

There are three principal types of cooling: (1) Part of the fuel circulates

GUIDED MISSILES & PILOTLESS AIRCRAFT

between the walls of a double-wall construction before being injected into the combustion chamber; (2) Part of the fuel is injected radially into the combustion chamber through a large number of small drilled passages, after which the fuel follows along the wall during the burning process; and (3) The fuel cools an inner wall of the combustion chamber made of a porous material as the fuel passes through to the combustion chamber.

GUIDED MISSILES

A *missile* is a weapon which can be thrown or projected through space, such as a spear, an arrow, or a bullet. Each of these objects is guided along its flight path at the moment of its launching, but thereafter it is subjected to various external forces that affect the accuracy and speed with which it flies toward the target.

A *guided missile* may be defined as a weapon which travels through space and carries within itself a means for controlling its path of flight. This includes bombs, rockets, and, in the broad sense of the definition, even conventional airplanes. However, a *guided missile* must be one which can be launched in one direction, then changed in flight to hit another target.

The guided missile may operate from ground-to-air, ship-to-air, ground-to-ship, ship-to-ship, ground-to-ground, ship-to-ground, air-to-air, air-to-ground, and air-to-ship, depending entirely upon the place of launching and the target. Furthermore, the same type and model of guided missile may be used in two or more of these classifications. For example, an air-to-ground missile may be employed successfully as an air-to-ship missile, although all of the possible combinations of uses are not necessarily equally efficient.

A missile may be dropped from an airplane like a rock, fired from a gun aboard an airplane, or launched with its own power.

The method of propulsion may be any of the engines which we have considered in this book, that is, the missile may be powered with a reciprocating engine, athodyd, pulsejet, turbojet, propjet, rocket, or combination of two or more of these types of engines.

In design, it may or may not have aerodynamic surfaces, that is, it may or may not have wings, ailerons, a rudder, an elevator and other surfaces for supporting it in flight or controlling its flight path. It is possible to have rockets made with or without wings, and with or without stabilizing fins. Eliminating all sources of propulsion except rockets, it is obvious that a rocket is a guided missile only if it can be directed in flight to change from one target to another, regardless of any other features of its design and construction.

A guided missile may be controlled by an autopilot set in advance and thereafter not controlled from the launching personnel, controlled by an autopilot subject to radio-control from a "mother" airplane, or controlled by radar.

There are several methods of radar control. In one, the missile contains only a receiver and is controlled from a transmitter on a "mother" airplane. In another method, the missile is set for a certain target, released, and thereafter automatically follows every move of the target, leaving the "mother" airplane free to continue on its own course, assuming that it was launched from an airplane.

JET AIRCRAFT SIMPLIFIED

CONSOLIDATED-VULTEE 774

The Consolidated-Vultee guided missile known as the 774 is a rocket which is 32 feet long and the first U. S. Air Force missile approaching the size of the German V-2, which was about 45 feet long. The 774 was first fired successfully by Air Force technicians at White Sands Proving Ground, New Mexico, in the summer of 1948, and is regarded as a training missile.

This rocket was designed to test the operation of advanced types of rocket vehicles and for experimentation with new launching techniques, handling devices, fuels, and rocket-propulsion engines. In addition, it is suitable for upper atmosphere research, being one of the few rocket vehicles available potentially capable of attaining altitudes of more than 100 miles.

It has a long, needle-sharp nose and four movable control fins. The center diameter is about 30 inches. Liquid fuel is used. The speed is far above the speed of sound.

The principle underlying this fully automatic, target-seeking guided missile resembles that of a live bat which makes little pulsating sounds and is guided by echoes from his own sound, thus finding his way through the dark without colliding with anything. This system was applied in the "BAT", the first fully automatic missile successfully used in combat by any nation. It was developed by the National Bureau of Standards under the sponsorship of the U. S. Navy, and is mentioned as an example of target-seeking control and not necessarily because of any other application to rocket power.

There are many other methods of giving a guided missile target-seeking properties. For example, it is possible to guide a missile by means of the light, heat or sound emitted from the target, or emitted from some object which can be used as a reference point for guiding the missile to the target. Likewise, the sun, moon and stars may be used in the automatic, target-seeking navigation of a missile, but a further discussion of control methods is beyond the scope of this text.

Both the Army and the Navy have a wide variety of guided missiles powered by rockets. The Consolidated-Vultee 774 and the North American NATIV are good examples of ultra-modern rockets which are true guided missiles. The multi-stage rocket described later in this chapter can be developed into a guided missile, but at present is intended only to serve as an experimental device for studying a means of obtaining extra speed and altitude from rockets that will go beyond the atmosphere of the earth.

Obviously, a military guided missile carries an explosive charge called a "warhead" in its nose. The warhead is not shown in the illustrations accompanying this chapter but it is, nevertheless, an important part of a missile in time of war.

NORTH AMERICAN NATIV

The "NATIV" is a guided rocket-test missile made by North American Aviation, Inc., as a test vehicle for the U. S. Air Force to use in aerodynamic research, development of control systems, and the training of rocket-launching crews. It was first fired at the Holloman Air Force Base, Alamogordo, New Mexico, in the summer of 1948. It uses liquid fuel, the length is about 13 feet, the diameter is about 18 inches, it has four movable control fins, and a long, needle-sharp nose. The speed is far above that of sound.

GUIDED MISSILES & PILOTLESS AIRCRAFT

THE MARTIN VIKING ROCKET

The first American-designed high-altitude research rocket, the Viking, illustrated in Fig. 6, was built for the U. S. Navy by the Glenn L. Martin Co., and initially launched at the White Sands Proving Grounds, Las Cruces, New Mexico, May 3, 1949. This single-stage upper atmosphere rocket reached an altitude of 51½ miles, and attained a speed of 2,250 miles per hour, which is three and one-half times the speed of sound.

Altitude was not the primary objective in the first flight because the chief purpose was to test the functioning of the power plant and control systems. Research instruments are carried for studying cosmic rays, atmospheric composition, radio propagation, photography and spectroscopy. This 45-foot long rocket was developed to replace the German V-2 in carrying scientific instruments above the earth's atmosphere. The power plant was developed and manufactured by Reaction Motors, Inc., of Dover, New Jersey, and was the most powerful and efficient liquid rocket engine developed at the time of its first launching.

The Viking has recently attained a speed of 4,100 miles per hour and an altitude of 136 miles, which is the world's record for single-stage rockets. The liquid oxygen-alcohol power plant that drove the Viking to that record altitude develops about 20,000 pounds thrust, and was also manufactured by Reaction Motors.



Fig. 6. The Martin Viking rocket.

JET AIRCRAFT SIMPLIFIED

THE NAVY GUIDED MISSILE "LARK", MADE BY FAIRCHILD

Another of the Navy's newest subsonic guided missiles is the LARK which is manufactured by Fairchild Aircraft Co. Fig. 7 is an artist's conception of this missile that is powered by a rocket motor developed by Reaction Motors, Inc. Performance characteristics are still classed as restricted military information.

MULTI-STAGE ROCKETS

Rocket experimenters have been attempting for many years to build multi-stage rockets having detachable sections that would drop off into space, one at a time, after their fuel was exhausted. Dr. Robert H. Goddard, known as the American "father of rocket research" obtained a patent on a multi-stage rocket but did not succeed in building it.

During World War II, the Germans made an anti-aircraft rocket called the "Rheintochter" (Rhinemaiden), which was driven into the air by a booster charge that dropped away after climbing a mile and a quarter. However, an actual multi-stage rocket was never sent to great heights until recently.

In February, 1949, the U. S. Army Ordnance fired a two-stage rocket at the White Sands Proving Ground, New Mexico. It rose about 250 miles, which is more than twice the best height (114 miles) ever reported for the V-2, and definitely beyond the gaseous atmosphere of the earth.

This first successful multi-stage rocket was made from a German V-2, but its warhead was replaced by the small rocket developed by the United States and known as the "WAC Corporal". When the combination reached a certain unspecified altitude, the WAC Corporal was fired by electronic control. It left the nose of the V-2, gained new speed in addition to the speed of the V-2 that it had already, and reached a speed of about 5,000 m.p.h.

The V-2, having served its purpose, dropped off and fell about 20 miles from the launching site. The WAC Corporal was tracked by observers equipped with special instruments and appeared to fall about 80 miles north of the launching site. Thus, the Army Ordnance engineers have the honor of being the first men known to project an object outside the atmosphere of the earth.

MILITARY LIMITATIONS ON LONG-RANGE ROCKETS

Long-range missiles that are flown and controlled by aerodynamic forces, such as the German V-1 missile, are vulnerable to interception when they are employed in ground-to-ground operations. This makes such missiles less efficient than the larger and more complicated long-range rockets, such as the German V-2, which do not depend upon aerodynamic forces.

The long-range rocket will probably become the best long-range offensive weapon because it is mobile, it is not susceptible to enemy interception, and it is cheaper than bombardment aircraft. It will not take the place of either artillery or bombardment aircraft if it is designed so that all control must be exercised during the first portion of its flight.

During the descent portion of the flight path of the long-range rocket, the friction with the air may cause the missile to burn.

More fuel is needed for long ranges. This increases the size and weight of the missile and is a fundamental limitation on its practical use.



Fig. 7. Artist's conception of the Navy Fairchild "Lark".

JET AIRCRAFT SIMPLIFIED

THE NAVY GUIDED MISSILE "REGULUS", MADE BY CHANCE VOUGHT

General Characteristics

The *Regulus*, a guided missile developed for the U.S. Navy by the Chance Vought Aircraft Division of the United Aircraft Corporation, Dallas, Texas, was designed for launching from submarines, surface ships and shore bases. Launching equipment can be installed in a short period of time on several types of vessels at relatively low cost and with only slight modifications to the vessel itself. In appearance the *Regulus*, Fig. 8, resembles a conventional swept-wing jet fighter, about 30 feet long.

A Navy Project

The *Regulus* program started in 1947. The U.S. Submarine *Tunny*, recommissioned on the Pacific Coast, was specifically modified to launch the *Regulus*. The *Tunny* was a converted World War II submarine that was modernized by the addition of a snorkel and streamlining the hull and conning tower. While in the shipyard, a tank for stowing a guided missile and a launching rack were installed.

A small group of officers and enlisted men on the *Tunny* were specially trained for a year at the U.S. Naval Air Missile Test Center at Point Mugu, California, in the operation and maintenance of the *Regulus*.

Although the assault missile, and certain other missiles employ a drone version of the *Regulus*, tactical employment would also include those techniques and guidance systems associated with the operation of all-weather, distantly controlled guided missiles. Such plans would make it possible to use the missile in various ways without the expense and effort of designing and procuring a separate missile for each function.

Testing and Training Versions of the Regulus

The test and training versions of the *Regulus* are equipped with tricycle landing gear so that the missile can be recovered upon completion of the flight. This recovery feature is important because the missile is not lost after each flight. A flight test vehicle, during the early stages of development, approximates the cost of a jet fighter. To evaluate a jet fighter, about 100 hours of flight time are required. To obtain the same flight test information on a non-recoverable missile comparable to the *Regulus*, about 200 missiles would have to be used if each were expended. The recovery feature therefore permits the number to drop to about 30.

In addition, much important test data, which might be lost if the missile were destroyed, are recovered and used to good advantage in subsequent flights. Several test missiles now in use have been flown many times at subsonic and supersonic speeds and have been recovered without damage.

The Navy has reported that as many as ten flights have been made with a single vehicle, cutting to one-tenth the cost of a comparable operation involving loss of a vehicle or missile for each test. Experience in landing the *Regulus* has shown that it can be recovered through the use of a parachute-type brake on an average runway.

GUIDED MISSILES & PILOTLESS AIRCRAFT

Tactical Version

The tactical version of the Regulus has no landing gear but carries a powerful warhead.

The armed forces plan a wide use of the Regulus missile, as both tactical weapons and recoverable test vehicles. Tactically, the Regulus will be used against appropriate land targets and in amphibious warfare it will be used by both the U.S. Navy and the U.S. Marine Corps. The recoverable version is being used to train operating units in launching and guidance techniques and can be used as a high speed drone for anti-aircraft guided missiles and anti-aircraft gunnery.

Remote Control

Before 1936, the Navy started several projects to fly aircraft by remote control. These projects met with varying degrees of success, but for reasons of weight, lack of dependability, and cost, not only these projects but similar projects of the other armed services remained generally in the development stage. In 1936, however, the Navy Bureau of Aeronautics started the development of a full-size remotely controlled maneuverable target airplane to provide a means of assessing the effectiveness of the fleet's anti-aircraft defenses. This project was successful.

Radio controlled target aircraft were first made available for fleet firings in October, 1938, and since that time have been provided in increasing numbers, both in peace and in war, and in all those parts of the world in which the ships of the U.S. Navy have operated. This project, when viewed in the light of history, might be considered to mark the beginnings of the Navy's effort to use guided missiles.



Fig. 8 The "Regulus" shortly after take-off.

JET AIRCRAFT SIMPLIFIED

Chance Vought Definition of Guided Missile

Based partly on their development of the Regulus, the engineers of Chance Vought define a guided missile thus: *A guided missile is an unmanned vehicle moving about the earth's surface, whose trajectory or flight path is capable of being altered by a mechanism within the vehicle.*

Notice that this definition does not include any mention of size, shape, speed, power plant, direction of travel, or employment. It is based upon the belief that a guided missile can assume any form, may travel on predetermined paths or on ballistic trajectories, may move at slow or supersonic speeds, and may be used for various purposes in both peace and war.

Navy Requirements for Guided Missiles

The Navy guided missiles are laid down to satisfy specific Navy operational requirements. The missiles are designed to extend or improve the defensive and striking power of its combatant units and fleets. The shapes of Navy missiles vary extensively, depending upon the function which the missile is designed to perform. All Navy missiles, however, have one common characteristic: *They are remotely or automatically controlled and, therefore, do not require in their operation those characteristics normally associated with the piloting of conventional aircraft by human pilots.*

THE AEROJET SOUNDING ROCKET

The *Aerobee* is a free-flight, fixed-fin-stabilized sounding rocket designed and manufactured by the Aerojet Engineering Corporation, a subsidiary of the General Tire and Rubber Co., Azusa, California. The *Aerobee*, shown in Fig. 9 coming off the assembly line, is used primarily as a vehicle to transport scientific instruments on nearly vertical flight. It can reach an altitude of more than 400,000 feet with a nominal payload of 150 pounds.

Launchings have been conducted by the U.S. armed forces from the White Sands Proving Ground, Holloman Air Force Base, and from the U.S.S. Norton Sound off the coast of Peru and in the Gulf of Alaska.

By making it possible to investigate the upper atmosphere for conditions of temperature, composition, density, magnetic-field, cosmic ray intensity, X-ray intensity, winds aloft, etc., the *Aerobee* has been the medium for obtaining valuable scientific data heretofore unavailable. Since the initial launching in 1947, the *Aerobee* has been the most widely used and least expensive research sounding vehicle of its general type in production. It is reliable and simple in design and operation.

The *Aerobee* is powered by a bi-propellant liquid rocket and is initially accelerated by a large JATO (Jet-Assisted-Take-Off) booster rocket which detaches and falls away when the booster thrust loses its punch. Helium pressure is applied to the vehicle propellant tanks to cause the propellants to flow into the thrust chamber for combustion. The JATO booster is electrically ignited from a control room at the time of launching. After reaching a high velocity during powered flight, the *Aerobee* then coasts with decreasing velocities to the zenith altitude at which time nose ejection may be accomplished for parachute recovery of the nose section.



Fig. 9. "Aerobees" just after coming off the assembly line.

The Aerobee vehicle is 20 feet long and 15 inches in diameter. The JATO booster which is used for launching adds another 6 feet to the overall length. Welded construction is used throughout the design. The main body section of the vehicle is an integrally welded stainless steel tank assembly. The pressure tank, which contains helium for expulsion of the liquid propellants, is located ahead of the oxidizer and fuel sections of the tank assembly.

Launching is accomplished from a tower approximately 150 feet in height. The tower is required to provide guidance in the initial period until the velocity is sufficient for the fins to provide aerodynamic stability. The launching towers in New Mexico were both designed and erected by Aerojet Engineering Corporation. The towers are provided with a tilting mechanism which allows compensation for observed winds in order to maintain impact within the limits of the test range. Therefore, limitations imposed upon launching schedules by weather conditions are minimized.

Experimental data are sometimes recorded in flight and then recovered by parachute. While in other flights, the test results are transmitted by radio from the Aerobee and recorded at ground receiving stations. Approximately six cubic feet of space is available in the hermetically sealed nose compartment for the instruments.



Fig. 10. The B-61 "Matador" at take-off.

GUIDED MISSILES & PILOTLESS AIRCRAFT

THE U.S. AIRFORCE B-61, MARTIN MATADOR

Fig. 10 shows the U.S. Air Force B-61, also known as the *Martin Matador*, taking off from a mobile launching platform. This is a ground-launched, medium-range, tactical pilotless bomber or guided missile, manufactured by the Glenn L. Martin Co., Baltimore 3, Maryland. It was designed and built for the U.S. Air Force Research and Development Command. The first tests were made on June 21, 1951, at the U.S. Air Force Missile Test Center, Cocoa, Florida, where the missiles were fired toward the prepared targets in the Bahama Islands. Before that, tests had been conducted at the Holloman U.S. Air Force Base, New Mexico.

The first Pilotless Bomber Squadron (Light) was organized and equipped with the B-61 missiles at Cocoa, Florida, on October 1, 1951.

This B-61 is a swept-wing missile which constitutes a completely integrated weapons system whose flight path can be controlled either from the ground or from an accompanying airplane.

It is powered with a single turbojet engine, originally an Allison J33, but obviously a more powerful engine today. Additional thrust at launching is provided by a solid-propellant rocket, which is jettisoned a few seconds later when expended, after which the turbojet engine provides all power. In flight, the missile is tracked by radar stations and information is telemetered back to the base. Other aircraft also provide information about the flight of the B-61.

THE RYAN Q-2 FIREBEE JET-PROPELLED PILOTLESS TARGET AIRCRAFT

The *Ryan Q-2 Firebee*, a jet-propelled, pilotless, target aircraft is shown on the ground in Fig. 11. An Air Force crew man adjusts the nylon webbing riser from which the Firebee is suspended in parachute recovery. This craft is a high-speed target for modern defense weapons. It is a mid-wing, all metal type with sharply swept-back wings and tail surfaces. Its cost is a small fraction of that of fighter aircraft with comparable performance.

It is built by the Ryan Aeronautical Company of San Diego, California. The powerplant is a Fairchild J-44 turbojet engine of about 1,000 pounds thrust. The speed is comparable to that of modern fighter airplanes. The length is about 18 feet and the span about 12 feet. Its altitude is from sea level to high altitude bombing levels. The rate of climb is similar to that of a fighter airplane. In maneuverability, it can simulate the maneuvers of a piloted jet airplane.

The gross weight is about one-tenth that of an average fighter airplane, or about 1,800 pounds. It is controlled by commands from a remote "beeper" pilot through conventional remote control links. It can be launched either from a "mother" airplane or from a ground launching device. The recovery of the airplane is either automatic or command by two-stage parachute system capable of recoveries at speeds up to 600 miles per hour.



Fig. 11. Ground view of the "Firebee".

CHAPTER X ROCKET-POWERED AIRCRAFT

THE GERMAN V-2 AS A POWERPLANT

The German V-2 was a guided missile used during World War II. It was not a *true* guided missile from the present point of view because it was not possible to launch it toward one target and then direct it against an entirely different target. In this chapter, we are interested in the V-2, not as a guided missile, but as an example of rocket propulsion which has influenced the thinking of those who have designed rocket engines for aircraft.

The V-2 missile was 45.8 feet long. The take-off weight was 28,020 pounds. The weight empty was 8,635 pounds. The nose and shell of the warhead accounted for 410 pounds and the high-explosive charge in the warhead weighed 1,740 pounds.

Fig. 1 is a schematic diagram of the V-2 powerplant which shows the sequence flow of fluids. This drawing was made by Roy Healy and published in *AVIATION* Magazine. It is used here by permission of the copyright owners.

The engine burned a combination of liquid oxygen and ethyl-alcohol. These were forced into the combustion chamber by turbine-driven pumps driven by superheated steam produced by the decomposition of hydrogen peroxide.

The drawing shows the alcohol tank and the oxygen tank. The upper tank held 8,400 pounds of 75% ethyl-alcohol solution in water for a flight of 155 miles. The lower tank held 10,620 pounds of liquid oxygen. These tanks were insulated from the outer shell by layers of glass wool.

During the early stages of burning, air ram pressure was supplied on the alcohol. When the V-2 reached an altitude high enough for the air to be reduced to a sufficiently low density, this air line was shut off and the nitrogen cylinders supplied the pressure on the alcohol. A small quantity of the liquid oxygen was vaporized to supply pressure on the alcohol and then returned to its tank.

Directly below the nitrogen pressure bottles in the drawing is the tank which contained 285 pounds of 80% concentrate hydrogen peroxide. Beside it is the small tank filled with 35 pounds of potassium permanganate in saturated aqueous solution. The eight high pressure nitrogen bottles held about 30 pounds of nitrogen gas used to operate the valves in the power section. The flow of high-pressure nitrogen from the bottles to the valves was electrically controlled from the instrument compartment.

The V-2 was raised to its vertical position before being fueled. The alcohol, peroxide, oxygen, and permanganate were pumped into their tanks.

Two Roman candles were inserted into the combustion chamber on the opposite ends of a whirling arm and electrically ignited, thus forming a pinwheel that shot flame and sparks all around the chamber. The main tank valves were opened electrically from the outside, permitting the force of gravity to pull the fuel around the pump rotors and down into the combustion chamber where it was burned. The resulting generation of gases caused the turbine flow control valves to open and about 58,000 pounds of thrust was developed for take-off.

JET AIRCRAFT SIMPLIFIED

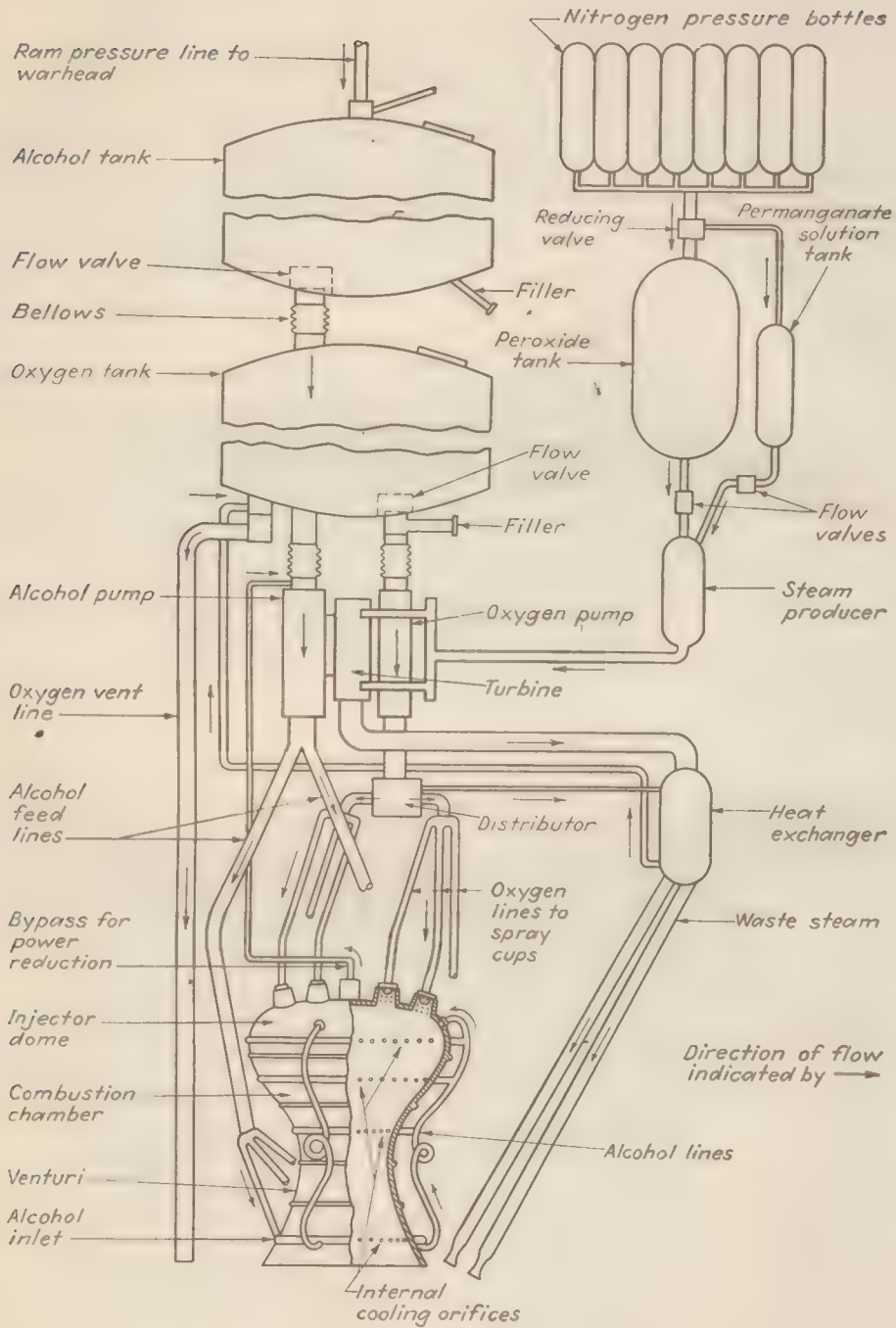


Fig. 1. A schematic diagram of the V-2 powerplant.

ROCKET-POWERED AIRCRAFT

About three seconds after the Roman candles were ignited, the V-2 took off.

The V-2 had a single-stage *steam* turbine. The peroxide and permanganate flowed into the steam producer. The permanganate acted as what the chemists call a catalyzing agent in breaking down the peroxide to produce super-heated steam and gaseous oxygen at high temperature. These were carried to a distributor ring near the turbine and from the ring through branch lines to the turbine nozzles, where the steam drove the turbine.

After leaving the turbine, the waste steam and accompanying chemicals were carried through a heat exchanger, the purpose of which was to vaporize a tiny quantity of liquid oxygen which was then sent to the oxygen tank to maintain its internal pressure. Also, the heat exchange reduced the back pressure in the steam line to help the operation of the turbine. The turbine rotor shaft was used to drive two pumps which fed the alcohol and oxygen to the engine.

While all this was going on, the hot burning gases were exhausted quickly to the rear and produced a thrust of about 60,000 pounds. The V-2 was not highly reliable in operation and its fuel consumption could not be called economical, but it reached an altitude of from 55 to 60 miles and traveled at a speed of about 3,000 miles per hour, or about 50 miles per minute.

THE REACTION MOTORS, INC., MODEL 6000C4 ROCKET ENGINE

The Model 6000C4 rocket engine, manufactured by Reaction Motors, Inc., is a rocket powerplant designed to drive piloted aircraft at velocities greater than the speed of sound. It is the first engine of its type designed and manufactured in the United States.

This unit is a liquid-propellant regenerative rocket engine which develops almost instantaneously a total thrust of about 6,000 pounds, or fractions of total thrust in increments of 1,500 pounds. Its total weight is 210 pounds and it occupies a space approximately 19 inches in diameter by 56 inches long.

It is easy to install in an airplane. The only connections that are required are connecting the engine to the airframe at four mounting points, attaching the two propellant feed lines to the manifold inlets on the engine, and connecting the electrical lead wires into a standard socket on the engine control box.

Fig. 2 is an indexed view showing the cylinder, fuel check valve, evaporator coil, mounting bracket, igniter assembly, oxygen check valve, nitrogen bleed connection, high tension lead, binding strap, fuel manifold, oxygen manifold, and nitrogen manifold.

Fig. 3 is an indexed view showing the ignition coil, high tension lead, igniter feed control valves, mounting bracket, evaporator coil, cylinder, binding strap, jet nozzle, oxygen inlet, fuel inlet, oxygen check valve, and fuel check valve.

The engine consists fundamentally of four combustion cylinders plus all the necessary piping, wiring and controls, supported by a single main beam assembly. With minor exceptions, such as piping, wiring, and the control box, the entire unit is constructed of high grade, stainless steel. The major components of the engine are almost entirely of welded construction.

JET AIRCRAFT SIMPLIFIED

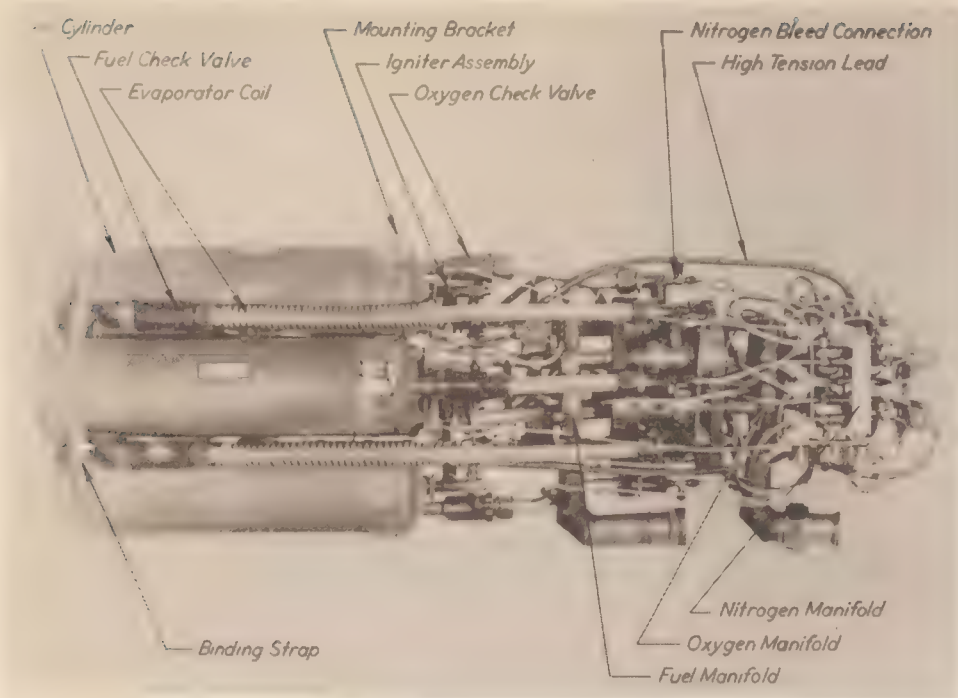


Fig. 2. An indexed view of the 6000C4 Rocket Engine

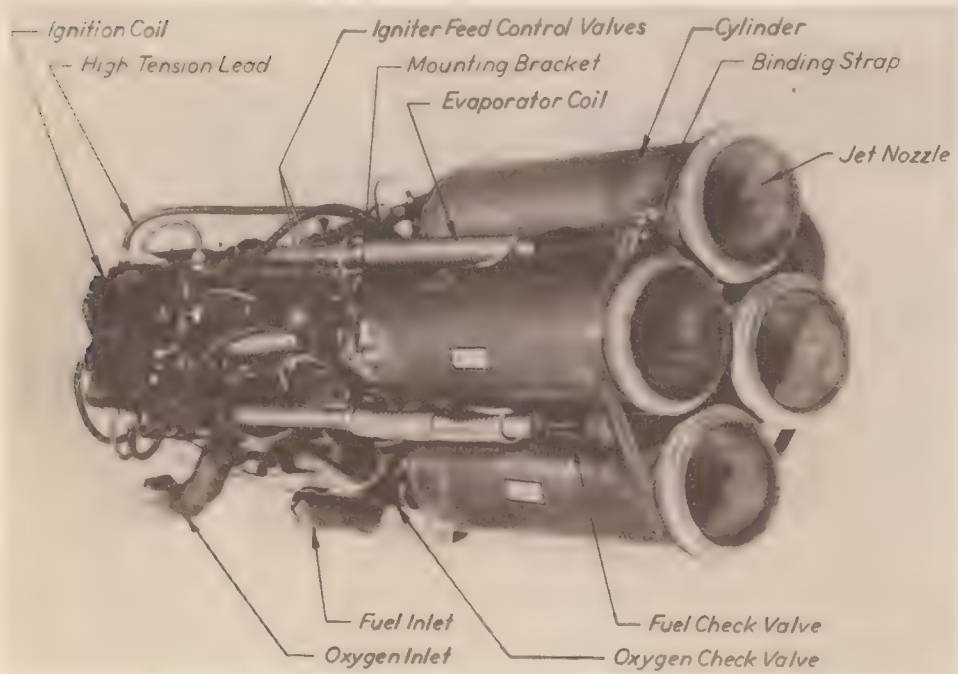


Fig. 3. Another indexed view of the 6000C4 Rocket Engine

ROCKET-POWERED AIRCRAFT

The engine operates from the controlled combustion of a fuel and an oxidizer. These propellants are injected under pressure into a combustion chamber where they are thoroughly mixed and ignited. The rearward expulsion of the combustion products through the nozzle in the form of a jet of hot gases develops the forward thrust.

The major components of the engine are the main support beam, the control box, the propellant manifolds (fuel and oxygen), the propellant valves (of which there are two types—fuel and oxygen), the igniters, and the combustion cylinders. The main beam assembly, as its name implies, is provided to support all the other components as a single unit.

All phases of the operation of the powerplant are regulated by the “master-mind” control box. The fuel and oxidizer enter the propellant manifolds from their pressurized tanks. Their pressure regulated by the propellant valves, the propellants flow to the combustion cylinder where they are mixed in the injector and sprayed into the combustion chamber. The igniter, itself a miniature rocket engine, sets off the exhaust nozzle with a terrifying roar and at tremendous velocities of about 6,500 feet per second. Theoretically, in the exceedingly thin upper atmosphere an aircraft could be propelled at the speed of the jet.

The combustion in the rocket engine takes place in the combustion chamber at a very high pressure, and because of this as well as because of the energetic nature of the propellants used, a rocket engine develops intense heat (4,500-5000° F.) on the combustion cylinder walls. To offset this, the combustion cylinders of the 6000C4 are so designed that the liquid fuel, before entering the combustion chamber, passes between the inner and outer cylinders.

The fuel cools the walls and in turn the heat from the walls tends to evaporate the fuel before it is injected into the combustion chamber. This principle is known as regenerative cooling, because the heat absorbed by the fuel is returned to the combustion chamber. This method of cooling is so effective that the stainless steel nozzle and combustion wall do not suffer any erosion or over-heating even after several hours of operation. The external temperature of the cylinders rarely exceeds 140° F.

Since alcohol and liquid oxygen do not ignite spontaneously, an igniter has been developed to initiate the combustion. The igniter is a very small rocket engine attached to the head of each combustion chamber. It is fed the same propellants as the main combustion chamber and is started with a spark plug and may be turned on or off at will.

One of the requirements in designing this engine was that it should be capable of repeated starts and stops in various attitudes, including firing with the nozzles pointing 30° upward. In order to comply with these requirements, a special injector had to be developed. This was done and the engine can be started easily in any position. Positive ignition has been obtained even when the combustion chambers of all cylinders were tilted up and filled with water before starting.

THE BELL AIRCRAFT CORPORATION'S X-1 SUPERSONIC RESEARCH AIRPLANE

The first man-carrying supersonic aircraft made in the United States was powered by the Model 6000C4 rocket engine made by Reaction Motors, Inc. This airplane was the X-1 manufactured by the Bell Aircraft Corporation.

JET AIRCRAFT SIMPLIFIED

The X-1 was of conventional shape, having a wing area of 130 square feet, an aspect ratio of 6, and a wing loading at the beginning of its flight of 100 pounds per square foot. It was 31 feet long and had a span of 28 feet. The pilot was enclosed in a sealed cabin. Behind him within the fuselage were tanks carrying liquid oxygen and alcohol feeding for 4.2 minutes a 6,000-pound rocket engine mounted in the tail. At launching, it weighed 13,034 pounds, and burned more than 8,000 pounds of fuel to land weighing 4,818 pounds at a speed of about 110 miles per hour. A tricycle landing gear was used.

It was anticipated that wing wake interference over the horizontal tail would present difficulties in transonic flight. For this reason, the horizontal stabilizer was placed as high as was considered feasible above the wing wake and was made rapidly adjustable to accommodate large changes of trim. The control surfaces were made conventional and unboosted because the small size of the airplane precludes the probability of unmanageable stick forces.

In selecting the powerplant, the desire to have the airplane take off under its own power ruled out any serious consideration of engines of the ramjet family. Another reason was that little was known about athodyds and pulsejets when the Army first approached the manufacturer regarding its design in December, 1944.

After reviewing the powerplant field, the choice was narrowed to turbojet and rocket propulsion. Preliminary studies indicated that an airplane designed around existing turbojets, using the thrusts given in the engine specifications, would not attain the tentative requirements of a minimum speed of 800 m.p.h. for 2 to 5 minutes at an altitude of 35,000 feet or more, and an ability to carry 500 pounds of recording instruments.

It was found that speeds in the region of only $M = .90$ (90% of the speed of sound) could be obtained at sea level with the then existing turbojets and that performance at altitude was considerably less. The manufacturers of turbojets were asked to increase their engine outputs at altitude by 100 percent or more for short periods of time by any means possible. Very little had been done then on thrust augmentation, and the demand for production models prevented any development on a specialized project.

The Bell engineers then considered a combination of a turbojet with a rocket engine. The turbojet would be used for take-off, climb to altitude, and return to the home base. The rocket would be used to accelerate the airplane to, and maintain the desired speed after, the operational altitude had been reached.

This study of a combination powerplant resulted in tentative plans calling for an excessively large airplane. The turbojet performance fell off at altitude, resulting in a poor rate of climb, which in turn called for a large amount of fuel. The speed at which the airplane was flying when the operational altitude was reached was also low, requiring a considerable amount of rocket fuel for acceleration purposes. The use of such widely different powerplants also increased the installation and operational problems.

Although the fuel consumption of an all-rocket powered airplane was high, the rate of climb was also high, averaging better than 20,000 feet per minute between sea level and 35,000 feet, with a climbing speed of 500 miles per hour. Thus, the fuel required for climb was relatively low and that required to accelerate from climbing speed to the desired test speed was less than with the com-

ROCKET-POWERED AIRCRAFT

bination turbojet and rocket. At higher altitudes the potential climbing speeds and rate of climb were even greater, reaching maximum values of 120,000 feet per minute at an altitude of 120,000 feet, flying at nearly 1,400 miles per hour. After a comparative analysis of the design studies made around the various powerplants, it was decided to proceed with the all-rocket powered airplane.

Several propellants were considered, among them being hydrogen peroxide, acid with aniline, nitro-methane, gasoline with liquid oxygen, and liquid oxygen with alcohol. Each of these was examined on a basis of *specific impulse*, which is the thrust per pound of propellant consumed per second. The safety and cooling factors of the various fuels were also taken into consideration with the result that liquid oxygen and alcohol were chosen as the propellants for the X-1's engine.

FLIGHT OPERATIONS

In order to obtain the tremendous increase in potential performance resulting from the launching of the X-1 from another airplane, a standard B-29 was used. Its bomb doors were removed and the X-1 was suspended from a standard D-4 bomb shackle. An enclosed ladder was installed between the B-29 and the X-1 so that the X-1 flight personnel could go back and forth between the two airplanes while in the air. Fig. 4 shows the X-1 in flight by itself.

In October, 1947, Captain Charles E. Yeager, U. S. Air Force, became the first man to fly at supersonic speeds in straight and level, as well as climbing flight, when he flew the X-1. Since then, the Air Force has repeatedly announced flights faster than the speed of sound and at more than 60,000 feet elevation.

The X-1 took off under its own power for the first time on January 5, 1949, and climbed to an altitude of 23,000 feet in 1 minute 40 seconds. Later, the X-1 was presented to the Smithsonian Institution, Washington, D.C., for public exhibition. One of the two airplanes built under the X-1 designation was retained for flight research by the N.A.C.A.

THE BELL X-1A

The *Bell X-1A*, another airplane in the X-1 research design series, underwent flight tests at the Air Force Flight Test Center, Edwards, California. On completion of the tests, it was turned over to the U.S. Air Force Air Research and Development Command to obtain data which could be applied in the further development of high-performance aircraft.

The X-1A, shown in Fig. 5, includes engineering improvements and is larger than the original X-1, although there is a marked resemblance. The engine was built by Reaction Motors, Inc. and has a thrust of at least 6,000 pounds. The fuel consists of liquid oxygen and a special alcohol-water mixture. The National Advisory Committee for Aeronautics will continue to work with the U.S. Air Force on the Bell X-1A as part of the continuing research program.



Fig. 4. The Bell X-1 in flight near Murco Air Force Base, California.

ROCKET-POWERED AIRCRAFT



Fig. 5. Ground view of the improved and enlarged Bell X-1A.

ROCKET POWERED DOUGLAS "SKYROCKET"

Another research aircraft that has been carried aloft by a mother ship, is the Douglas D-558-2 Skyrocket. Fig. 6 shows the Skyrocket just after it had been dropped from the mother ship at an altitude of about 35,000 feet to proceed on its rocket motors only. This airplane, powered by one of Reaction Motor's liquid propellant engines with a thrust of 6,000 pounds, has flown higher and faster than any other man-carrying craft — 83,235 feet and 1,238 miles per hour.



Fig. 6. The "Skyrocket" in free flight just after leaving mother ship.

JET AIRCRAFT SIMPLIFIED

ROCKET POWERED REPUBLIC "XF-91"

Fig. 7 shows the Republic XF-91, which is the first interceptor-type aircraft fully loaded for combat to have exceeded the speed of sound in level flight.

This airplane is powered by a turbojet with afterburner as well as a 6,000 pound thrust liquid propellant rocket engine that was developed by Reaction Motors, Inc.



Fig. 7. Republic Aviation's XF-1 in flight.

JET-ASSISTED TAKE-OFF (JATO)

The purpose of *jet-assisted take-off*, abbreviated JATO, is to help an airplane take off with heavier loads, shorter runs and greatly accelerated speeds. JATO has been developed principally by Aerojet Engineering Corporation, a subsidiary of General Tire and Rubber Company.

The standard aircraft JATO is a rocket engine producing 1,000 pounds of thrust for the duration of 14 seconds. It has a solid propellant consisting of 70% potassium perchlorate (oxidizer), 20% asphalt, and 10% S.A.E. No. 10 oil (fuel). Fig. 10 is an indexed picture of the unit, showing the cap assembly, and the safety-cap. Fig. 11 is a cutaway picture of the same unit with the charge assembly and the attachment lugs labeled.

ROCKET-POWERED AIRCRAFT

The assembly consists of one stainless steel cylinder closed at the front end to provide a container for the propellant cartridge, with the combustion chamber, exhaust nozzle igniter and safety valve at the rear end. The thrust is taken through three mounting lugs welded to the cylinder for attaching the unit to an airplane. The weight of the engine is 200 pounds loaded and 120 pounds empty.

When the JATO applies its push or thrust, the active force is transferred to the body to be propelled through attaching connections which securely fasten the jet engine to the propelled body. The operation is not affected by external temperature and pressure conditions. It is as reliable as any internal-combustion aircraft engine.

Fig. 8 illustrates the take-off of a TACA Airways DC-3 transport from a high-altitude airport in Nicaragua, assisted by two JATO units. Fig. 9 shows the take-off of a Pan-American transport. The pilot can determine the amount of thrust at any time by glancing at instruments in the cabin. The passengers are not frightened by the take-off because they cannot see or hear the JATO engines in operation. Actually, the jet exhaust from the JATO units is a white smoke containing no more carbon monoxide gas (CO) than the exhaust gases of an internal-combustion airplane engine.

The added acceleration is not appreciably noticeable. The airplane at take-off employs all of its engines and the additional thrust given by the JATO units is applied gradually enough to be scarcely apparent.



Fig. 8. The take-off of a TACA Airways DC-3 transport from an high-altitude airport, assisted by two JATO units.



Fig. 9. The take-off of an American Airlines transport, assisted by JATO units.

The JATO units cannot injure an airplane. A safety plug with a breakable diaphragm is provided in each unit to safeguard against excessive pressures that may be accidentally generated in the reaction chamber, as shown in Fig. 10.

The attaching mechanism does not add greatly to the weight of the airplane or its cost. It is simple and inexpensive, and may be fastened to any substantial member, either of the fuselage or the wings. The unit can be reloaded by replacing the expended propellant by a cartridge type charge after the unit has been examined and reconditioned. The unit does not require much time for installation because it is installed in a supporting bracket with greater ease than a bomb is placed in the bomb bay of an airplane and just as easily as a bomb is placed in an airplane bomb shackle. Units arrive from the manufacturer ready for installation and use.

JATO units can be used successfully in "instrument" take-offs because they provide the additional thrust that makes up for the loss of "small fractions of a second" through instrument lag, pilot reaction, controls operation, and other factors.

The principal advantage of JATO for light airplanes is that its use enables pilots to take off from small airfields or emergency spots which are adequate for landings, but not large enough for take-offs with ordinary power.

JATO makes it possible for the light amphibian or seaplane to take off from small lakes, high-altitude lakes, or other bodies of water where ordinary engine power is insufficient for take-off.

ROCKET-POWERED AIRCRAFT



Fig. 10. A safety plug is provided in each unit to guard against excessive pressures.

On a glider, a JATO unit can be the sole source of power for take-off because it can launch the glider in a few seconds to a proper soaring altitude from any convenient airport, thus eliminating assembling and dismantling, hauling, and the expense and difficulty of airplane tows or other cumbersome launching methods.

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